

Historic, Archive Document

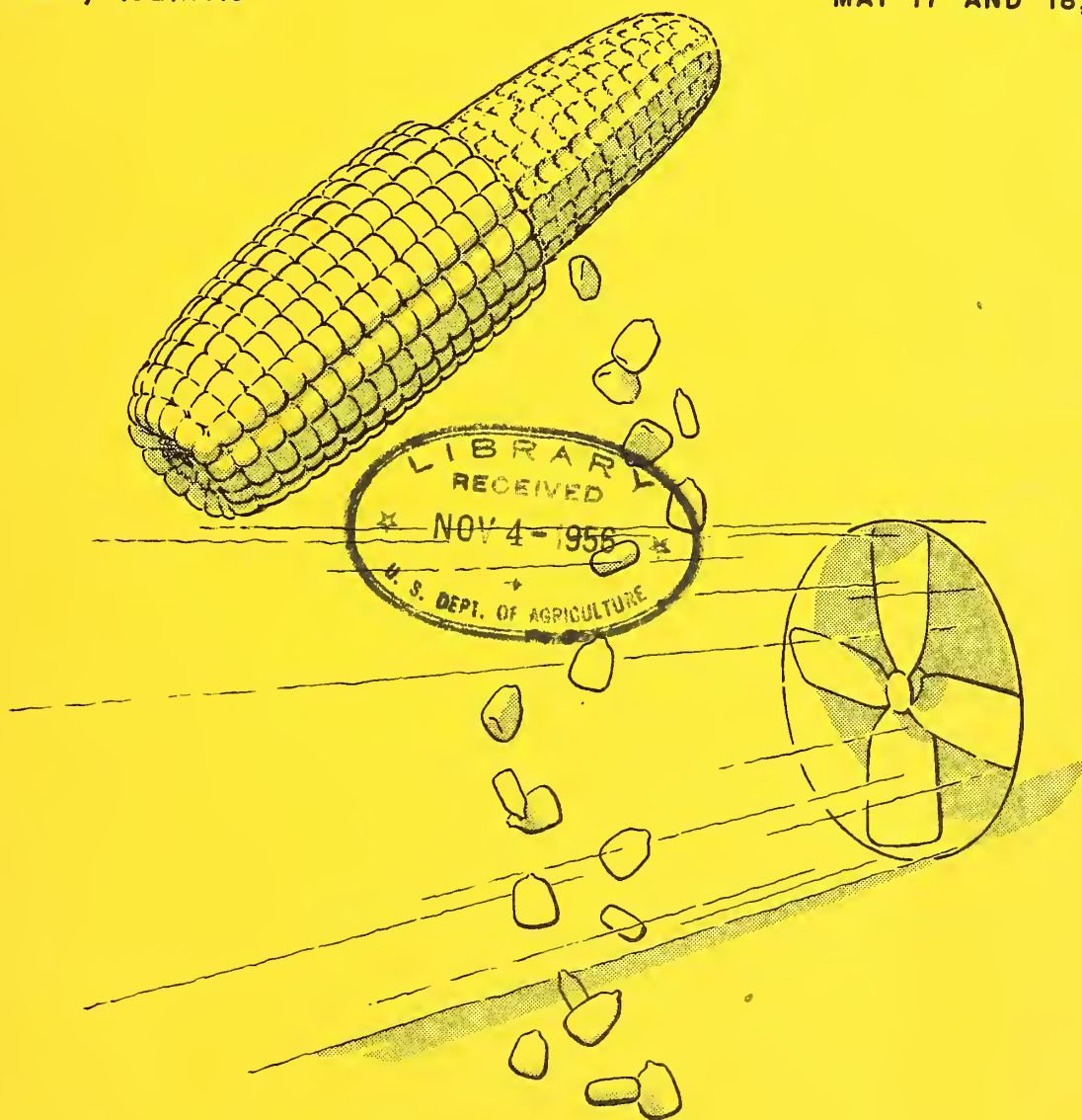
Do not assume content reflects current scientific knowledge, policies, or practices.

A59.9
R31

PROCEEDINGS OF CONFERENCE ON FIELD SHELLING AND DRYING OF CORN

CHICAGO, ILLINOIS

MAY 17 AND 18, 1956



SPONSORED BY
AGRICULTURAL RESEARCH SERVICE
OF THE
UNITED STATES DEPARTMENT OF AGRICULTURE

Classification

UNITED STATES
DEPARTMENT OF AGRICULTURE
LIBRARY

Conference

State Agriculture	25
U. S. Department	20
Agriculture	15
Agriculture	3
Federal Extension	1
Rural Electrification	1
Crop Drier and	29
Farm Machinery	33
Farm Structure	14
Farm Buildings Equipment Manufacturers	3
Electric Power & Controls Manufacturers	4
Grain Marketing and Processing Trades	4
Farm Press	5
American Society of Agricultural Engineers Staff	2
Consulting Engineers	1
Unclassified	5



BOOK NUMBER

A59.9
R3i

913536

* * * * *

Abbreviations:

ASAE - American Society of Agricultural Engineers
AERB - Agricultural Engineering Research Branch, ARS
AMS - Agricultural Marketing Service, USDA
APHRB - Animal and Poultry Husbandry Research Branch, ARS
ARS - Agricultural Research Service, USDA
FES - Federal Extension Service, USDA
NURB - Northern Utilization Research Branch, ARS
PERB - Production Economics Research Branch, ARS
REA - Rural Electrification Administration, USDA
USDA - United States Department of Agriculture

Issued August 1956

CONTENTS

	<u>Paper</u>
Purpose of Conference - Harold E. Pinches	A 1 - 6
Field Shelling, Drying and Storing High-Moisture Corn as Seen By:	
Farm Machinery Manufacturers - John Ransom	B 1 - 4
Crop Drier Manufacturers - Frank J. Zink	C 1 - 4
Farm Structures Manufacturers - Earl D. Anderson	D 1 - 6
Requirements and Limitations in Drying High-Moisture Corn:	
Corn Shelling Damage and Crop Losses - Geo. E. Pickard	E 1 - 3
Corn Harvesting Efficiency - C. S. Morrison	F 1 - 2
Maturity of Corn in Relation to Field Shelling - S. R. Miles ...	G 1 - 13
Limitations on Drying and Storage Imposed by Growth of Molds -	
Clyde M. Christensen	H 1
Quality Requirements of Market Corn - Leo E. Holman	I 1 - 3
Relationship Between Drying Conditions and Nutritive Value of	
Corn - R. E. Davis and C. A. Cabell	J 1 - 5
Principles of Drying - W. V. Hukill	K 1 - 9
Drying Systems:	
Unheated Air Drying-In-Storage - G. M. Petersen and	
J. W. Simons	L 1 - 14
Supplemental Heat for Drying-In-Storage - H. J. Barre	M 1 - 8
Heated Air Drying of Shelled Corn - Nolan Mitchell	N 1 - 10
The Heat Pump for Conditioning Corn - Chester P. Davis, Jr.	O 1 - 10
Storage of Shelled Corn:	
Conversion of Facilities for Storage and Handling of Shelled	
Corn - E. A. Olson	P 1 - 7
Maintaining Quality of Dry Corn in Storage by Forced-Air	
Cooling and Aeration - Leo E. Holman	Q 1 - 3
Farm Management Relationships:	
Introductory Statement - O. J. Scoville	R 1 - 2
The Farm Manager Looks at Corn Harvesting and Storage	
Alternatives - Douglas F. Graves	S 1 - 8
Farm Management and Economic Problems Accompanying Field	
Shelling and Artificial Drying of Corn - Roy N. Van Arsdall ..	T 1 - 13

Paper

Research Status and Needs:

The Status of Public Research on Picking and Shelling Corn -	
L. W. Hurlbut	U 1 - 11
Status of Research on Farm Drying of Shelled Corn -	
Wallace Ashby	V 1 - 13
Research Needs - C. K. Otis and R. R. Poyner	W 1 - 3
Outline of Research Problems Related to Field Shelling and	
Drying of Corn	X 1 - 4

State and Federal Projects on Field Shelling and Drying of Corn	Y 1 - 3
---	---------

User Training and Education:

Report on User Training and Educational Needs - J. B. Stere	Z 1 - 2
The Diffusion and Acceptance of New Ideas as Related to Field	
Shelling and Drying of Corn - Dale O. Hull	ZZ 1 - 3

* * * *

Opening Statement

by

Harold E. Pinches, Assistant Director,
Farm and Land Management Research,
Agricultural Research Service, U. S. Dept. of Agriculture

I want to welcome you all here. I do that as a representative of the Administrator of the Agricultural Research Service of the U. S. Department of Agriculture.

A few of us happened to be talking last winter about field shelling and drying of corn, and we began to recognize that here is a wave of new technology starting in American agriculture which can be wide spread and important in its influences. It occurred to us that while considerable research has been done at various times and places, a lot of new industries are coming into the field, i. e., new to harvesting corn in the field at higher moisture contents, or coming into the storage and drying of the corn. As we talked, a question was raised whether a Conference would be desirable to bring together research people from the Department of Agriculture, from the Experiment Stations, and from interested industries to exchange ideas; to find out whether there is sufficient information available from past and present research on the drying of corn and other grains, and the problems associated with it, both in the field and at the farmstead; whether this information is fully available to the people who can use it, particularly the people in companies just coming into the field; and what information should be put together in one way or another for the farmer, or to use in your training and educational programs.

We look upon the job of education as two-fold; part of it must be done by the public agencies, particularly the Extension Services from the various states, and much of it, of course, by the industries selling products. It involves dealer training, salesman training, and farmer training.

We wondered whether the persons who could use such information knew what was available and where to get it. We became interested in what problems farmers are facing in using this new equipment. We wished to learn what, if any, new research is needed.

Therefore, two of the main purposes of this Conference are to find out the educational needs and research needs.

We recognize that the harvesting and handling of corn at higher moisture contents involves several industries in an unusual degree of inter-relationship and mutual inter-dependence. At least these industries are involved: The machinery people, the farm tractor and implement manufacturers; the crop dryer manufacturers; structures and structural equipment suppliers; materials handling equipment, i. e., elevators, conveyors, and so on; control apparatus for measuring temperature and humidity of the air and moisture content of grain; electric power companies, since much of what we are talking about today would not be of any interest to a great many farmers

if it were not for the fact that power lines have become available to practically all farms in the United States; fuels, for sources of heat, are, of course, involved; and there are no doubt others that I have not mentioned.

This involves a rather unusual situation. The field hay baler, for example, is primarily a matter of concern to the farm machinery manufacturers. When the hay is baled, and tied up with twine or wire, it is in a package and the baler manufacturer is done with it basically. But when the same farmer purchases a picker-sheller, or attachment for a combine, for harvesting corn in the field at 20 or 25 percent moisture, the manufacturer is not done with it by any means because the corn isn't going to keep unless it is given proper treatment. There is a whole chain of events and equipment and industries that need to be interrelated.

So when the question was raised, is a Conference desirable to discuss all these interrelated factors, we soon came to the conclusion that such a meeting would be desirable. That is why we are here today.

I want to indicate clearly a few things that this Conference is not concerned with. It is not concerned with -- and this is a decision which was made by the planning group, which I will tell you about in a moment -- this Conference is not concerned, except incidentally, with the drying of corn for special purposes, or special markets, such as the seed corn trade, or the wet millers. We recognize them, of course, as important. They have their special drying problems, and special requirements, but, as we saw it, those needs are concerned with a few hundred million bushels at most. Farmers, however, are concerned with three billion bushels of corn that go into feed. Moreover, because of the widespread use of hybrid seed corn in this country, we don't even need to be concerned with the viability of the corn to be dried (except seed corn), as we do need to be with other crops.

We are not concerned in this Conference with other methods of storing corn, but we do want to recognize that there are other methods and make clear that we are not here to pronounce that drying is the only way to store high moisture corn. Farmers have been storing high moisture corn for a long time, as when they chop stalks and ears into the silo.

Recently there has been interest in some quarters, and by some companies, in the storing of ears of corn or shelled corn in certain types of silos at moisture contents too high to store in ventilated structures.

We recognize there are those systems and, as research people, we are interested in them all. But we chose for this Conference to concentrate on the problems of the harvesting and safe storage of high moisture corn by drying processes.

Incidentally, the representatives of at least one company interested in high moisture storage without drying are here, if any of you are interested in talking to them about methods other than drying. I am sure the reason they are here is to get ammunition from you birds who are trying to sell dryers, to see what is wrong with dryers, so they may know what to tell their sales department about their equipment.

This is an invitational Conference. We concluded that one of the things necessary was to keep the Conference to a reasonable size, so it could be a working conference. We have arrived this morning at just about exactly the size we thought would be very desirable. Although this is an invitational meeting, it is not closed, there is nothing confidential here. Our purpose is to develop a set of "proceedings" which will be published in due course and available from the Department of Agriculture through the Agricultural Engineering Research Branch of the Agricultural Research Service. These proceedings will be available to anyone.

We have asked all speakers to provide at least a summary of their remarks to be included in these proceedings. One of the purposes of having a register is to get your name and address, so we can send a copy to you who are here, without further work on your part. If there are other persons whom you think would be interested in having a copy of the proceedings, give us their names and addresses, and they will be taken care of just as you will be.

We conceive this to be a working Conference. While we have a program, everyone in the audience is part of this Conference, and we hope for questions and discussion. We have already indicated that we are not here to sell or promote any system or any types of equipment. Our view is that the success of any system or equipment will rest ultimately on its technical soundness and on economic advantages to the farmers. If it cannot meet those two requirements, if it can't meet both of them, it won't last long.

So we invite you to ask questions, to examine all of the statements that are made here quite critically, to get acquainted with each other and thresh out problems that there may not be time for discussion from the floor.

Now, a word about how this Conference was put together. After some conversations last winter with some individuals who were active in the field, and some exchange of correspondence, we felt probably a conference of this nature was desirable. So, in March, we called together about twenty persons and spent two days here in Chicago, first going over the question "Is a conference desirable?" It did not take long to settle that question affirmatively.

We spent the rest of the two days in the development of ideas for a program. The nature of the Conference, and most of the program were determined at that meeting of, as I said, about twenty persons, some of them from the Department of Agriculture, men from at least three of the Agricultural Experiment Stations, and men from industry -- we had representatives from three or four of the farm machinery companies, representatives from the structures field, and the crop dryers and so on. We tried in that planning group to get a good cross section of the interests that might be concerned with a meeting of this nature.

Then we depended on those persons to suggest names of people who should be invited. We depended on associations, also, like the Farm Equipment Institute and the Crop Dryer Manufacturers Association, to suggest names of persons who should be invited.

Again, let me make it clear, we have no intention of excluding anyone. If we overlooked anyone who should have been invited, it was unintentional. On the other hand, we were not trying to get a big crowd to fill a big auditorium. We wanted to get a representative group small enough to talk together, and out of that get a set of proceedings which would keep in print what we together come out with in these two days. We believe this procedure will make available to everyone interested, who is not here, much of what he would have gotten, or his company would have gotten, if he were here.

We are looking on this as national in scope. It may look regional, maybe partly because this is the center of the Corn Belt, but we are quite conscious of the fact that the boundaries of the Corn Belt are getting very shifty. Some of the most interesting developments in the growing and harvesting of corn are in areas that have not been thought of as corn country. So this is not intended to be, in any sense, a regional Conference. It was held in Chicago because we knew that so many persons from the Experiment Stations, and particularly from the industries interested in the subject of this Conference, could get here easier than probably any place else.

The program. I will run through it very hurriedly to give you a sense of what we had in mind putting this program together. The first hour and a half will be a quick run over the field to get a kind of bird's-eye view of what is going on now that was not in existence just a few years ago. We have asked representatives of the machinery manufacturers and crop dryer manufacturers and the structures field, and a couple of persons with practical experience on farms to tell you what they are seeing in each of their areas, and what they are seeing from their viewpoint as to problems and opportunities if and when the development is complete all across the board.

Then we will give you some indication of publicly supported research, both at the Agricultural Experiment Stations, and in the Department of Agriculture, which is pertinent.

In the afternoon we will get down to the technologies involved. We felt that one of the things this Conference could do, would be to bring out the framework in which corn can be harvested and dried, and what the hazards are from the technical standpoint, both mechanical and nutritionally.

Corn may be safe to keep if it is dry, but perhaps things happen to it that are not desirable from an animal husbandry standpoint. I don't want to be misunderstood on this. There is the possibility that there could be some undesirable aspects from a nutritional standpoint, and that is the reason we have brought in the nutritional approach. It may be the other way around, there may be advantages, and we want to bring that out, if that is true.

This evening we are having two roundtables, one to consider research needs, and the other the user training and educational needs. You are free to go to either one by your own election. Or if you want to sneak out, you are free to do that, too!

Tomorrow we will get busy with what you might call the mechanics of drying and storing, the physical relationships of drying and storing high moisture shelled corn. There is where we bumped into a problem in this field, and that is that people don't use words to mean the same things. There isn't any standard terminology yet in the field, as we discovered in our program planning session.

So we spent a little time on that, and with no attempt to establish -- we were not in a position, certainly, to establish words that would be used by everybody henceforth -- but to avoid some confusion at this Conference, and to allow everyone to understand more quickly what any speaker may be talking about, we agreed upon the phrases that are exhibited on that board.^{1/} They are put up there only for the sake of helping when any speaker says, "I am talking about No. 1," or No. 3. It seemed to us that basically there were four types that we should recognize. These are rough and crude distinctions we know, but they are better than we started with when we first started discussing the matter of terminology.

There seemed to be, in rough terms, three systems of drying corn. One is by the pumping of air through the corn and depending upon the drying capacity of the air only, without the addition of any heat. That was conceived to be a process slow enough that it would probably be done where the corn was put in storage, as in a bin, where it was going to stay for at least a number of days or a few weeks, or perhaps until it is fed out, so the first one (No. 1) is "unheated" air, characterized also as "Drying in Storage." Any one of these systems, of course, can be used in drying in storage. There is nothing exclusive about that for No. 1 or No. 2. However, trying to distinguish basic differences which would probably generally be met, we felt that one system could be distinguished as drying in storage with unheated air. With some addition of heat, still comparatively a slow process, then you would have No. 2, the "supplemental heat-drying in storage" system.

System No. 3 is involved with generally different types of equipment. It can be done, of course, in storage, but it is the type that is likely to have associated with it auxiliary equipment in which corn is put for one to, at most, a few days, and enough heat applied so that that batch of corn is dried and gotten out of there. Then another batch will be put into the drying chamber, using the drying chamber many times during the season. A variation of this may be a system which involves essentially a continuous flow of the corn through a drying apparatus, and from there on into its ultimate storage or, of course, off to market.

1/ Basic Systems for Conditioning and Storing High Moisture Grain

1. Unheated Air - drying in storage
2. Supplemental Heat - drying in storage
3. Heated Air - batch or continuous drying
4. Aeration-Cooling - to maintain quality of grain in storage

Then we recognize that some of the equipment we are talking about might be used by a farmer who had corn he knew he was going to feed out during the winter. He might have no reason for drying it, but just to keep it from spoiling by ventilation, so we add the fourth, "aeration." Ventilation is involved, also, in the long-time storage of corn, even after it is dry, such as Commodity Credit Corporation storage when corn is kept for perhaps several years. That corn has already been dried, but there are problems and we felt that should be brought into the picture here.

As I said earlier, there are two tests that have to be met by any system, or any equipment. One is that it is technically sound. The other is that it fits in advantageously into the farming system, and that is the major topic of our Friday afternoon session. We are fortunate in having in that case some men who have been studying the changes and practices and the problems on farms where driers are already in use and have been in use for some time.

Then, toward the end of tomorrow afternoon we will ask the two roundtables which will meet tonight to come in with statements of research needs and education and training needs.

DEVELOPMENTS IN FIELD SHELLING,
DRYING AND STORING HIGH MOISTURE CORN

- - as seen by Farm Machinery Manufacturers

by

John Ransom, Product Research Director
Minneapolis-Moline Co., Minneapolis, Minnesota

It is indeed both an honor and a pleasure to appear here. I am happy to contribute to clarifying what appears to some of us to be a confused and chaotic situation. The subject, "The Situation as Seen by the Field Machinery Manufacturers," brings up the question, "can we clearly see it at all?"

We in Minneapolis-Moline Company have been selling picker-shellers for, I believe, five or six years, with a good degree of success. We note with natural interest that some other machinery manufacturers are now developing field shelling machinery.

This is no place to discuss the relative merits of one type of machine over the other. We will assume they all harvest and deliver the shelled corn.

Here let me make one thing clear. I can hardly speak for other machinery manufacturers, but I can give you a few thoughts from the experience of Minneapolis-Moline. We know some of our problems. The problems that we are confused with are not primarily with our own machines, but with the involvement of other machines and processes when field shelling corn, rather than harvesting by older and more time-honored methods. So we come to the question, why have we developed the picker-sheller?

Of course, probably the first and simplest answer is that we thought we saw an opportunity to do some business, and jumped in.

But the farmers and others say, "Well, why go to the trouble of shelling it all if you are going to feed it on the farm," the area with which this Conference, I understand, is concerned. They say, "Why not let the animals shell it? We have fed our corn for many, many years with considerable success." Or others say, "Why not let the grinder handle it and grind the cob along with the kernels?"

Numerous knowledgeable and time-honored institutions in this Nation have published papers showing the value of feeding cob meal along with the kernels.

And we have the time-proven process, that Mr. Pinches mentioned, of putting the whole stalk, ear, kernel, and all in the silo and feeding and utilizing every bit of the corn crop.

There are many, many problems. Our customers and prospects ask us, "Why should I buy a picker-sheller?" Our salesmen speak up quickly and say, "You can harvest your corn earlier."

The farmers answer, "But it is too wet." Then we say: "Why let it stay in the field, for when the moisture content has reached somewhere between 30 and 40 percent, as is commonly stated, it has reached full maturity, with the greatest amount of dry matter developed. If you let it stay in the field longer than that, it can do nothing but deteriorate. Also if you harvest it early by the shelling method you only need to dry the kernels, you don't need to dry the cobs, and the whole process becomes sensible and practical. You get it off the field and avoid field losses. You dry it under controlled conditions, rather than under the natural weather conditions in the field, and avoid damage, such as stalks breaking down from wind, or from corn borers and so forth.

Then we say: "There is less material to haul and to handle, just the kernels, and that also is less to store. You remove only the kernels from the soil. You leave the cobs and the stalks, and all else go back in the soil from whence it came."

There are numerous other reasons why field shelling has been promoted and sold, why we are promoting and selling it now along with our competitors. However, it does stand on the premise, the whole field shelling thing, that if you get the crop off the field earlier, you must have some means of drying it, or store it wet. This conference, I understand, is on the subject of drying.

We also know that there are numerous problems in connection with field shelling, and these our prospects and customers ask us about and, unfortunately, so far, we often have to say, "You had better go see somebody else." "If I am going to dry corn," they say, "How am I going to dry it? Do I use heated air, a fan and furnace, or unheated air, or just the fan? Do I want to dry it continuously, or do I want to dry it in batches?" Some people have said, "How about induction?" I have seen it work in a forge shop and other places. And I notice, that heat pumps are one of the subjects on this program.

And then, too, I have been asked numerous times, "How about the use of high vacuum to dry this corn." I know of no place that it has been tried.

Numerous other subjects come up. Farmers say: "I want to shell it and get it off the field in a hurry so I can do other things, and avoid weather and other hazards, but how do I dry it?" And we, as the picker-sheller manufacturers, say, "We will shell it for you. From then on it is up to you."

Another unanswered question is when to dry it? I imagine my files would disclose at least a dozen letters dated in 1956 -- saying what we need to do is fix our picker-sheller so it will dry the corn as it goes up the elevator to the grain bin. Naturally, we would like to do that, but nobody has come forth with what appears to be a practical way to do it.

Some driers have been built with high volume b.t.u. capacity, with the thought or at least the suggestion from their shape and conformation that we dry it while we haul it from the sheller to the granary, and have it dry when it reached there. But, unfortunately, the moisture we want to remove is quite

great, and the time of hauling by modern methods is rather short to dry on the way.

There are the proponents of drying in storage, and those proponents of drying after selling, if you sell it. Some of those who sell feed, and buy corn say, "Let us buy it from you just as you harvest it, we have the drying facilities or storage facilities or other facilities, and then we will sell you the feed."

So the whole thing gets quite involved. We run into some very annoying things on our part, which I can only list as sort of assumptions, or old wives tales, about how we must shell it with a field sheller. One is that we must not ever crack any kernels or damage the wax coating on the outside, and this is stated in numerous other ways. We ask, "Why not?" And so far we have always been faced with just no answer.

Why not? What harm does a little damage to some of the kernels do? If some of them could be damaged a little, cracked, or maybe even ground in the process, some of the problems of field shelling would be different. But we go on the assumption if we shell it in the field it must come from the machine the same as it came from the sheller that shelled dry corn that had been in the crib all winter. By using separate equipment you can segregate damaged or broken kernels which might be stored or fed separately, or treated differently than the undamaged ones, if that is necessary or desirable.

But we continue to work on the assumption that we must deliver wholly undamaged clean kernels from the field shelling machine. All we can say so far is that we must assume that that assumption is proper and correct and necessary.

Then it is often said, "You must not parch, pop, discolor or anything else, in drying." And we ask, "Why?" And so far we have never received an answer.

I remember one fellow who had quite a drying set-up for alfalfa, and he used the phrase, "I dry it and feed my cattle toasted alfalfa." He was doing some kind of toasting-parching process, which he thought might have some virtue.

Then we get into cost figures, and I can only refer to a letter that some of our people sent out to the field the other day in which they had costs of field shelling as compared to costs of other methods, and I will swear, there was every figure in the book in it and none of them added up. We know almost nothing about costs. Farmers, approach us about this new process, about a machine we have built, or our competitors built, to field shell corn. Maybe somebody has good answers to give them. We tell them all we can but we feel that we need to know much more.

Handling shelled corn is much different from handling ear corn. Different equipment is required, both to convey it and to store it, and new feeding practices are involved. Shelled kernels are rather highly concentrated feed, when separated from the cobs, as well as the husks and the stalks.

There is a lot of knowledge on the subject, I am sure, but I am not sure that it is readily available to the farmer who wants to start this new practice. It is largely hidden back in the books or the papers somewhere.

There are numerous imbalances. A good field sheller might produce 1,000, 1,500 or 2,000 bushels a day. Let us say 750 bushels is a good day's work with average yields. But with long rows, and with a heavy yield a couple of thousand bushels are shelled out by a good operator in a day. If that is harvested at 30 percent moisture, and if it is to be dried to 12 percent, there is a real problem for the drying process to keep up with any such shelling production.

The rate of shelling, of course, is largely set by the rate of the picker. We have to start out with the approximate rate of a two-row picker, running two, three or four miles an hour, and that covers so many acres. We can't start field shelling at a much slower or faster rate. So we have a job of correcting the imbalances of operative rates of field shelling and handling-storing-drying equipment.

Then we have some other problems that I hope we will begin to correct. When a man adopts the new process of field shelling and drying, he must do several things at the same time, in that he is harvesting his crop, and has to dry it. If that requires any time or attention he must be two men, or much smarter than he has been in the past, or able to do or manage more, because he now has two things to do at one time.

Another example might be the corn-wheat-clover rotation where the farmer wants to get the corn off early in order to sow wheat. That may be his main reason for adopting the shelling and drying process. He then must harvest it, dry it, and work and seed the fields from which he had harvested the corn, all right at once, and that presents management as well as machine and labor, problems and confusion.

So I think we are beginning to know some of the questions, and hope as a result of this meeting, and perhaps through other activities of one kind or another also, we may soon know some of the answers better. In the meantime, we are going to keep on selling picker-shellers. I am sure our competitors are, too. I am sure the drier manufacturers are going to keep on selling driers; I am sure the structures manufacturers will keep on selling structures. I am sure the wet storage people will keep on selling wet storage facilities. Out of it all will probably evolve, we believe, a great new process, a great new technology or procedure on the farm. For we know that we got the good machines of today by selling and using the poorer machines of yesterday, and that we will get the better machines of tomorrow only by selling and using the good equipment of today.

Thank you.

DEVELOPMENTS IN HARVESTING, SHELLING, DRYING AND STORING

HIGH MOISTURE CORN

-- as seen by DRYER MANUFACTURERS

by

Frank J. Zink, Secretary
Crop Dryer Manufacturers Association

At the outset of organization of the Crop Dryer Manufacturers Association, a series of objectives was set up. These objectives adopted in 1952 were set forth in their constitution.

Since this is the first time that these objectives may be reviewed more broadly by others than those in our various membership categories, I believe it may be worth while to repeat them to those present here today. They are very broad, as you will note.

I shall quote these from the constitution of CDMA. They are:

"A - To promote and further the interests of the manufacturers of crop drying equipment, structures, and other accessories related to crop drying methods in problems of manufacturing, distribution, use, research, and educational and promotional industry advertising;

B - To promote such standardization of products as will best meet the needs of the Association and its individual members to further meet the needs of its equipment in service;

C - To collect and disseminate information of value to its members and to the public;

D - To provide for its members and for the industry suitable representation before legislative committees, Government bureaus, and other bodies in regard to matters affecting the industry;

E - To do such things as are permitted or required under regulation of the Governmental agencies to promote a spirit of cooperation throughout the industry for the improved production, proper and safe use, and increased quality and performance of its products in service of the public."

The accomplishment of such objectives has depended and will further depend on a number of factors. Funds and members' time are the main ingredients to the activities of the Association. Our members have been lacking in both but have done some very excellent work as is evidenced by some of the material which I will show you.

Among the membership of the Association are eleven regular drying equipment manufacturing firms. There are six affiliate firms, those firms who are generally classed as component suppliers. In addition to these dues paying members is a non-dues class of members who have been of a great deal of help to the Association. These mostly are college research people and also the farm press.

In the Association's organization it was provided that memberships on a non-dues basis would be available. Any interested individuals representing themselves or any organization especially of a public group are eligible. Basically the Association is a commercial organization -- but with this broadened aspect of inviting memberships, contributions and ideas from others who have an integrated interest. All funds expended have been derived from manufacturing members.

The total net expenditures of the Association from the beginning of activity to present date have been well under \$10,000.

While not all of our work will show up in any publication form, that which does show up I believe will be of interest to you.

Each contribution of the Association has been the result of committee assignment plans. All committees of the Association have been functioning on the open end basis. In fact, the Association being small in number has resulted in complete membership review of all items so far published.

First - Through some extensive study, discussions, preparation, revisions and objective testing through 1952 and 1953 the Association was able to adopt a testing and rating code. This code covers any form of crop drying equipment either for heated air or unheated air. This code, with slight revision of points not engineering in nature, has been published in the Agricultural Engineering Journal, June issue 1954. This appears as a proposed code to be reviewed by interested ASAE members. I believe no substantial revisions have been received -- at least none has come to my attention -- and it would appear now feasible for the ASAE membership to formally adopt the code.

In conjunction with such adoption, I wish to add a note of caution. I personally believe that no standard as established by this testing and rating code should become so statically entrenched that it would be a hindrance to progress.

Second - Although this conference is called and is limited to corn interest, I wish to call attention to the Association's publication "HOW TO LOWER FEEDING COSTS WITH BETTER QUALITY HAY." Inasmuch as crop dryers should be a universal unit on the majority of our farms, and inasmuch as hay drying is a most profitable procedure on the farm, to be rational many farmers will consider equipment selection to cover all crop drying needs.

Third - Following the booklet on hay, also in 1954 the membership produced the second eight-page booklet entitled "HOW TO GET BETTER FEED AND BETTER PRICES FOR YOUR GRAIN." This especially covers material of more direct interest to men in this conference.

Fourth - In 1956 through individual effort in collection and joint effort in review and adoption a supplement to the grain drying booklet has been adopted. This one-page item is entitled "GRAIN DRYING RECOMMENDATIONS". In addition to shelled corn and ear corn, eight other grain or food crops are covered. On behalf of the Association, I wish to be the first to admit that these are at present based on gleanings from current and past federal and state publications. We may not have reached all sources, and further our sources may not be in universal agreement. However, for the time being we feel that they represent an improved generalized review of material available. I may add that a careful summary of recommendations for changes is being acquired to revise or supplement this form.

The distribution of our publications has been modest yet very effective. There has been a gradual increasing demand. This demand has been more active the past few months than at any other time since our booklets became first available in 1954. We usually donate these when requested to public service agencies. We sell them to profit making firms at approximate cost. Total distribution to date has been around 90,000 copies. The ratio of interest based on circulation is slightly greater for hay. However, it is our oldest issue, and the grain harvest season demand is yet to come this year.

In this industry we are very conscious that the drying of crops is perhaps our most important objective. However, we are not limited to that activity alone. It will be noted that our code covers crop conditioning. This involves not merely drying. In the Association we are interested as well in preparation prior to storage, preparation for safe storage after placing in storage, keeping safe in storage over prolonged storage periods, and without doubt the potential need for reconstituting moisture in corn and other grains for feeding and marketing needs.

It is to be noted eventually about 90 percent of our corn crop is fed on the farm to livestock. However, hardly ever is any farmer in position to know clearly what he may do in any one year, and almost certain not to know in a succession of years. It would always be desirable, therefore, that crop drying place the farmer's potential decision in completely flexible atmosphere. Bearing directly on this is the incompatible situation that best prices for market grade of moisture content do not conform to moisture content for safe keeping, at least for prolonged periods.

The crop drying industry is being and must be integrated with harvesting, storage, handling and end use of all the crops which are produced in our agriculture.

In general, our farm equipment industry has been primarily concerned with production or individual product activity not so closely related to structures or farm practices as would call for major farmstead consideration. Here now in crop drying is a practice which calls for more field and farmstead integration of practices than the farmer has ever before had available to him.

At the present time the crop drying industry is struggling for the recognition of other agricultural agencies. It is not well off financially. It has, however, gained acceptance especially well in some places. Shelled corn drying has gained a foothold not to be denied in some corn producing

areas. Shelled corn drying in some new areas is now being adopted first and ahead of the older systems of corn harvesting.

The industry has some current research needs, but older ones too have those. Within the industry there are active a number of well qualified agricultural engineers. Fortunately too, other interested engineers are contributing generously to our progress. I would be remiss as an industry representative if I did not specifically mention the warm air heating and oil burner industries, the fan industry, the electrical industry, and the control people are listed among our most helpful agencies.

Most of all I wish to add that I believe our state and federal research in agriculture has provided us with the building material for a strong future. We will, I expect, hear from those present representing this industry of more detailed research problems which we may individually and collectively feel are in need of attention.

On behalf of the crop dryer industry as well as personally, I wish to commend the organizers of this conference. If we are to have a completely engineered agriculture, and I certainly believe we are attaining this, we should have such a conference as I expect this will be. Just recently I was somewhat surprised to learn that with a dryer any good farmer could rightfully expect to increase his cash corn income by at least 20 percent. For several years I have believed this possible, but my surprise was due to the fact that this theory has now reached the stage of an accepted farm management practice.

FIELD SHELLING AND DRYING

HIGH MOISTURE CORN

-- as viewed by STRUCTURES MANUFACTURERS.

by

Earl D. Anderson*

It is my pleasure today to discuss with you the structures required for storing high moisture or field corn and for maintaining high quality in storage. The farmer, of course, is just as interested in this third essential, storage, as in the harvesting and drying of the corn. Then he must combine all three of these elements with management for a successful operation.

I am happy to say at the outset, that structures need not be a bottle-neck in the farmers' plans to take full advantage of this new harvesting method. There are a number of storage structures commercially available to farmers today which will store this corn safely. In fact some of these structures are much more than just storage bins. Some have a built-in dryer as well as an aeration-cooling system to prevent moisture migration.

In the brief time at my disposal, today I should like to (1) give a general description of the current farm storage facilities for corn, (2) list the considerations for safe storage of field shelled corn and (3) describe the approaches by structures manufacturers to meet safe storage requirements.

Most of the permanent type farm corn storage facilities in use today were designed in the era when corn was harvested by hand rather than by mechanical methods. The most common is the open-slat ear corn crib ranging in width from six to twelve feet and in height from about ten to 25 feet. Some of these structures are tapered to a narrower width at the base in an effort to induce better natural drying. Many cribs were doubled with a driveway between and bins for small grain located above.

These conventional cribs are not only unsuited for storing field shelled corn without major alterations but they leave much to be desired as a proper storage unit for ear corn. The principal weaknesses may be listed as follows:

1. No provision for mechanical drying.

Machine harvesting methods result in faster filling of cribs less exposure to drying air in crib, with resulting greater chance of spoilage during storage. Farmers, also, may be unable to qualify for government storage loan because moisture content is too high.

* Director, Agricultural Extension
Stran-Steel Corporation
Ecorse, Detroit 29, Michigan

2. Subject to losses from rodents.

The open slat crib is an open invitation to rodents with their attendant damage unless special precautions are taken.

3. Too small capacity.

This is attested by the prevalence of temporary cribs. Many of these have been constructed each year on the pretext of an "emergency" which has recurred annually for the past twenty years.

The storage capacity requirements per farm have increased despite government acreage limitations. Principal factors are the trend toward larger farms and sealing of corn for government loans together with higher yields resulting from the use of hybrid seeds, more fertilizer and better cultural practices.

4. May be subject to losses from insects.

In the southern portion of the commercial corn area, corn can be stored only for a limited time in ear form without excessive insect loss. Open slat construction is not suited to fumigation.

5. Difficulty in moving ear corn.

Ear corn is difficult to move out of storage since it does not flow like shelled corn.

Ear Corn Drying and Storage Buildings

We should also, at least recognize the introduction in the past ten years of structures specially designed for drying ear corn in storage, harvested and handled by modern mechanical equipment. These structures are of several types. Some are built of conventional materials usually according to Midwest Plan Service Plans. Some conventional cribs have been converted to mechanical drying following these plans as a guide. And then there are pre-fabricated units - both the single-purpose vertical units and the multi-use horizontal units. Some farmers, anticipating the coming of the field-sheller have planned their ear corn drying buildings for easy conversion to shelled corn drying.

CONSIDERATIONS IN STORING FIELD SHELLED CORN

Having listed the inadequacies of conventional farm storage for ear corn, we might properly consider the case for storing the corn in shelled form:

1. Requires only 50% as much space as ear corn.

By eliminating the cobs, one bushel of corn requires only $1\frac{1}{4}$ cu. ft. of space instead of $2\frac{1}{2}$ cu. ft.

2. Rodents are excluded from the grain mass.

3. Insects more effectively controlled - easier to fumigate.

4. Grain in semi-fluid form easier to move.

Handier to move for mixing, feeding or marketing.

5. High moisture field-shelled corn must be mechanically dried.

Use of drying system helps insure quality and permits earlier harvest with resulting lower field losses.

6. Corn in shelled form must be mechanically cooled or turned to prevent moisture migration. Farmers generally do not understand the cause of crusting and subsequent spoilage - sometimes incorrectly blame dryer.

7. Storage structure must be weather-tight.

8. Structure subject to greater floor and wall pressures, but problem of lodging on tension cross brace members eliminated.

TYPES OF STORAGE UNITS AVAILABLE TODAY

Manufacturers have used several different kinds of approach to the storage or storage and conditioning problem.

Conventional Construction

These structures, either new or remodeled, are usually built by local contractors following plans of the State College or University, Midwest Plan Service or adaptations of these furnished by the basic building material producer such as wood or masonry.

Specifications for the construction of conditioning tunnels may be included in the plan, but the fan usually must be secured elsewhere and some engineering advice may be necessary.

Prefabricated or Factory-Built Structures

These structures may be bins with a capacity of 1000 to 3000 bushels or the larger multi-use flat or horizontal storages ranging from 2000 to 40,000 bushels or more. Usually manufacturers in this field can supply the complete pre-engineered package.

The bins, often of steel construction, may be used for storage only in connection with batch dryers. When equipped with perforated floor or a duct system, they may be used as batch dryers utilizing heated air or drying-in-storage units using unheated air. These bins are largely single purpose structures, but they provide a high degree of flexibility with respect to quantities of different grains.

The horizontal structures of the multi-use type likewise are well adapted to use with batch dryers when equipped with a mechanical cooling system to prevent moisture migration. They also are well adapted for drying-in-storage when furnished with an unheated air drying system which serves a dual function as a grain cooling system. These multi-use structures are not suitable for

batch drying with heated air, although supplemental heat can be supplied to the drying-in-storage system.

NEED FOR THE RESEARCH

Thus, we see there is a wide variety of structures available to serve the farmers needs in storing or storing and conditioning the high moisture corn.

Some of the manufacturers of these structures and the conditioning equipment have based their designs on extensive research programs. We know from actual field experience that high moisture shelled corn can be safely conditioned and stored by these various methods. Furthermore, that this combination of field-sheller, dryer and storage unit offers help to the corn producer in his present cost-price squeeze.

But we are now at the point where more research must be done if we are to bring the maximum benefits to the farmer from these basic developments. After all, the basic research programs in the tractor industry did not start until after some enterprising manufacturers first placed some tractors on the market. What farmer today would be satisfied with a tractor which did not reflect the benefits of their long time carefully planned research?

I should like to predict that the sales curve of the field-shelling equipment will rather closely follow the sales curve of prefabricated or pre-engineered structures and conditioning equipment. I believe the farmer no more wants to buy separately, and then assemble, the parts for a field-sheller than he does the components for the drying system and the storage structure. He wants them pre-engineered too, and available from a common source. But I believe many farmers want more than that. They want a grain storage, drying and processing center coordinated with a feeding operation.

The producers of prefabricated farm structures thus have a common problem and a common opportunity. I should like, therefore, to recommend that this group, in the interest of progress, consider banding together in some formal or informal organization for the purpose of sponsoring this much needed basic research on an industry-wide basis. Commendable research along these lines is already in progress at several of the State Agricultural Experiment Stations and at Stations of the U. S. Department of Agriculture. Some individual companies are now sponsoring certain phases of this research. But much greater progress could be made by a coordinated effort. I have assurance that the State and Federal Research agencies would welcome this industry's counsel and support.

Three segments of industry are represented at this conference. The manufacturers of field-shellers and conveying equipment have the Farm Equipment Institute. The manufacturers of crop dryers have the Crop Dryer Manufacturers Association. The manufacturers of farm structures -- bins and buildings -- alone have no industry organization. I would welcome the opportunity of discussing this further with any others of our industry during the next two days or later.

(Following this discussion Mr. Anderson showed a few lantern slides of typical storage structures.)

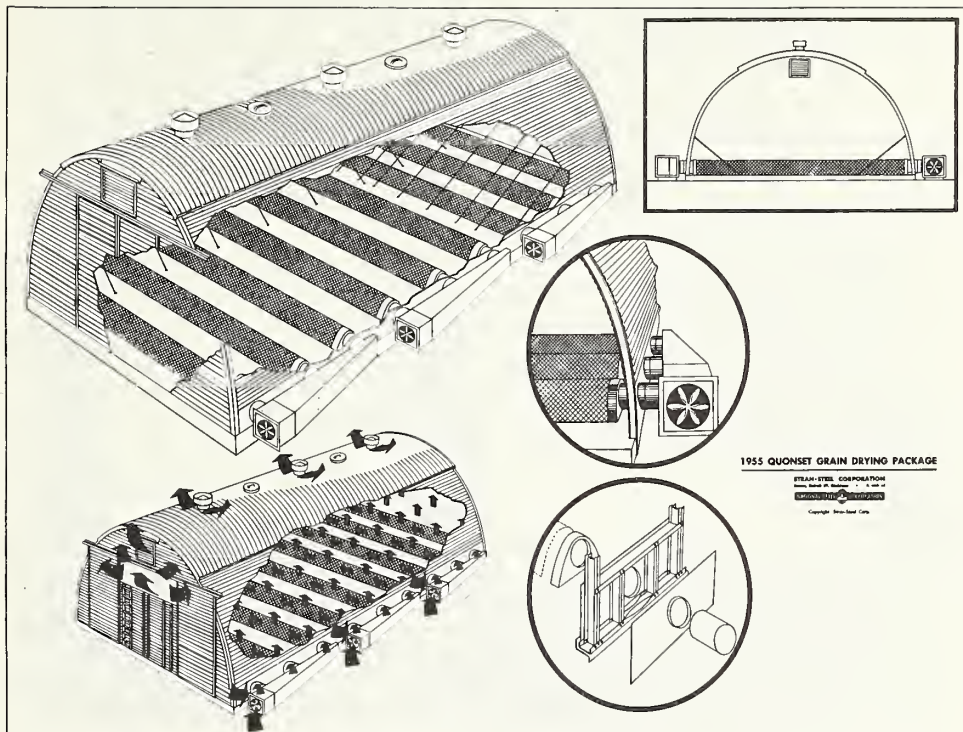


Figure 1.--(Top) Flat storage with cross-flues and multiple fans for drying grain with unheated air.
 Figure 2.--(Bottom) Exterior view of grain storage and fan equipment shown in Figure 1.



Figure 3.--(Top) Steel bins arranged with perforated floors for drying grain with unheated air.
Figure 4.--(Bottom) Steel bin arranged for drying grain with heated air.

CORN SHELLING DAMAGE AND CROP LOSSES

by

Geo. E. Pickard
 Department of Agricultural Engineering
 University of Illinois

In shelled corn harvesting, the operator must always strike a compromise in balancing the effects of early harvest, cylinder speed, and concave adjustment on picking loss, loss at the cylinder, and kernel damage. Early harvest reduces both ear and shelled corn loss at the snapping unit, but the high moisture early in the season makes the corn tough to get off the cobs, so cylinder loss is increased. In addition, moist corn is more vulnerable to damage and cracking.

High cylinder speed gets the corn off the cob effectively but increases kernel damage somewhat, so a compromise speed must be used. A close concave adjustment likewise reduces cylinder loss but increases damage.

These interrelationships and their effect on the farmer's income can be loosely expressed in the form of the following equation:

$$\text{Income} = \frac{\text{price (yield - losses)}}{\text{kernel damage}}$$

$$\text{Income} = \frac{\text{price (yield - (ear loss) - (shelled corn loss) - (cylinder loss) - (cleaning loss))}}{\text{kernel damage}}$$

Losses and kernel damage can be expressed in terms of the various factors affecting each.

$$\text{Income} = \frac{\text{price} \left[\text{yield} - \frac{1}{\text{early harvest}} - \frac{1}{\text{early harvest}} - \frac{(\text{moisture})}{\text{cylinder speed}} - \frac{(\text{concave clear})}{\text{cylinder speed}} - \text{loss cleaning} \right]}{\frac{(\text{moisture})}{\text{concave clearance}} \frac{(\text{cylinder speed})}{\text{concave clearance}}}$$

Substituting M for moisture and "early harvest"

C for concave clearance

N for cylinder speed

P for price

Y for yield

and introducing suitable constants and exponents, we have:

$$\text{Income} = \frac{P \left(Y - k_1 \frac{1}{M} - k_2 \frac{1}{M} - \frac{M^{n_1}}{N \frac{1}{n_2}} C - k_3 \right)}{\frac{k_4 M^{n_3} N}{C}}$$

With a little more data on these factors, it should be possible to establish average values of these constants and exponents, permitting a close prediction of losses, damage, and resultant income.

Now I would like to review some of the experimental results of our shelling experiments at Illinois since 1950. We will first of all look over these 1954 results, which represent the most carefully controlled and analyzed experiments.

Concave Clearance

It will be noted that changing from 5/8" to 3/4" concave clearance caused no significant change in kernel damage but an increase of about 1-1/2 percent in the cylinder loss. Hence it appears desirable to use the smaller clearance. Nevertheless, we must not go too far or we will break cobs excessively and provoke a separation problem. Taking the averages of all our work at Illinois, we find that the change from 3/4" to 5/8" steps up damage by only 4-1/2 percent while reducing cylinder loss 57 percent. This clearly shows that we should use as close a concave setting as we can without breaking the cobs too badly.

Cylinder Speed

The early experiments at Illinois indicated that a combine cylinder speed of 700 rpm for a 15-inch cylinder (corresponding to 475 on a 22-inch cylinder) should be close to the best speed for shelling corn under average conditions. The 1954 experiments bracketed this speed with tests at 600 and 800 rpm. It will be seen that, while the increase to 800 reduced cylinder loss from 5 to 1-1/2 percent it increased damage only slightly. The 1950 to 1955 average bore out this comparison. The extra speed increased kernel damage by 17-1/2 percent against a reduction in loss by 68 percent. Of course, excessive speed must be avoided, as tests indicate that damage tends to rise rapidly beyond 800 rpm.

Moisture

While cylinder loss appears the most sensitive to falling moisture content, we see that kernel damage also falls quickly. Fortunately, they both fall off very rapidly at kernel moisture well above the normal picking stage of 21 percent. On the basis of these experiments, it was concluded that little advantage is gained by delaying harvest once the corn is below about 28 percent moisture.

At this point I would like to refer to experiments with a picker-sheller in Minnesota.^{1/} The conclusions from this work in 1953 and 1954 were as follows:

1. Early harvesting of corn will reduce the field harvesting losses, which increase rapidly as the season progresses. Harvesting with the picker-sheller and drying is one method of harvesting the crop early.

^{1/} Strait, John; Keppel, R. V. and Meyer, V. M. Harvesting corn with a picker-sheller. Minnesota Farm and Home Science 12. 3 pp. 4 and 5.

2. Losses with the picker-sheller will be largely gathering and snapping roll losses.
3. Corn harvested with a kernel moisture content of 25 percent or less and with reasonable machine adjustments should grade No. 2 or better as far as the percentages of cracked corn, foreign material, and damaged kernels are concerned.
4. Frozen corn shells very well. Shelling was complete, and damage to the kernels was negligible over the entire range of 40 to 18 percent kernel moisture.
5. On the basis of our tests to date, we would recommend that harvesting with the picker-sheller start when the kernel moisture content of the standing corn has reached 26 percent. Sheller losses will not exceed 2 percent, and the kernel damage should be sufficiently low for the corn to grade No. 2. For feed grain one may start harvesting at a moisture content of about 28 percent.

These results correspond substantially with those reported earlier from Purdue^{2/} and shown partially in these slides from our report, which appeared in the July 1953 issue of the A.S.A.E. Journal. It will be seen that the cylinder loss fell off very rapidly below 25 percent moisture, and kernel damage dropped from 12 to 4 percent between 29 and 20 percent moisture.

In 1954, studies of picker losses were made on 34 farms by the Agricultural Economics Department of the University of Illinois. Most of their results compared closely with those of earlier studies except for two items:

1. Corn shelled at picking rolls represented two-thirds of the total picking loss as compared with the usual equal distribution between ear and shelled corn loss. However, in 1954 corn dried very rapidly and appeared to be particularly susceptible to shelling.
2. Losses were significantly higher in morning picking than in afternoon: 7.0 as against 5.0 percent for the fourteen sets of morning and afternoon tests. Ear loss was practically constant, but shelled corn loss jumped from 3.0 to 4.8 percent for morning picking. Most of these tests were at moistures below 21 percent, the median being at 19 percent.

The general conclusion that seems to be well substantiated by all these results appears to be that shelled corn harvesting, by combine or picker-sheller, should be started when the corn reaches a moisture of about 27 percent and that drying facilities should be designed to handle corn from 30 percent, since many farmers who have large acreages will begin at this point.

^{2/} Burrough, D. E. and Harbage, R. P. Results of performance tests of a picker-sheller. Paper presented at 1951 winter meeting of A.S.A.E.

Abstract of Paper
"Corn Harvesting Efficiency"

by

C. S. Morrison, Manager,
Product Development, Deere and Co.
Moline, Illinois

Performance tests on the John Deere No. 10 Corn Attachment and No. 45 Combine were reported. The snapping principle in this machine has proven to reduce field losses of shelled corn by as much as 50 to 75 percent. The corn harvesting efficiency problem was summarized as follows:

1. Gathering losses are frequently excessive late in the harvesting season. The plant breeders and the entomologist must share this responsibility with the equipment engineer; too many ears are lost before the harvesting machine enters the field.
2. Considerable progress has been made by the equipment industry in reducing the high snapping losses encountered late in the season. Further work is needed on this problem.
3. Shelling losses are usually not a major portion of the total field loss. However, a reduction in the shelling loss at high cob moisture contents would be worthwhile.
4. At the present time, kernel damage is one of the factors which often requires that harvest be delayed for approximately ten days subsequent to the maturity of the grain. Engineering work on plant breeding and cultural methods may prove to be a factor in permitting earlier harvest.

Discussion - Pickard and Morrison

- Q. Do the gathering losses shown on the chart include ears on the ground before harvesting, or is there an additional loss?
- A. (Morrison) These figures from the 1953 work in Minnesota include ears fallen prior to harvest. However, in 1954, the gathering losses were approximately three times as high as in the preceding year.
- Q. In an average year would there be more difference in gathering loss as you progressed through the season?
- A. (Morrison) The University of Minnesota publications have not defined an average year. In my opinion, the data suggest that 1953 was a favorable year for mechanical harvesting; 1954 was an unfavorable year.
- Q. Is similar data available regarding fields attacked by corn borer?
- A. (Pickard) No.

- Q. Regarding kernel damage on weight basis, can you translate this in terms of cracked corn - grade?
- A. (Morrison) Amount of visual kernel damage is somewhat higher than grade would indicate. One of the grading factors is the amount of finely cracked material passing a specified sieve size.
- Q. How can you get No. 2 corn on a certain date?
- A. (Morrison) I have no data that we can depend on to relate visual damage with commercial grade. The University of Minnesota found that kernel damage fell below the No. 2 grade maximum when the kernel moisture was below 26%.
- A. (Pickard) Grade is based partly on amount of finely cracked material and partly on percent of visibly damaged kernels. Three percent of finely cracked material and 5% by weight of damaged kernels is permitted in No. 2 corn.
- Q. Have any studies been made on amount of kernel damage in field shelling seed corn?
- A. (Pickard) I know of no information available.

MATURITY OF CORN IN RELATION
TO FIELD SHELLING^{1/}

by

S. R. Miles
Agronomy Department, Purdue University

The information in this paper should be considered in deciding whether to shell corn in the field and when to begin field shelling. While most of the data were obtained near Lafayette, Indiana, the principles involved in the conclusions are probably generally applicable.

Corn Maturity

I shall first discuss maturity of corn. Several investigators have reported on when corn is mature. Because some of our conclusions differ from those previously published, I shall discuss maturity in moderate detail and shall briefly state some of the probable reasons for the different conclusions.

Previous researchers considered corn mature when its dry-matter yield reaches the maximum. I accepted this definition at the beginning of my research. In this discussion, we consider when the corn is mature on a rather uniform area of land - not when single ears are mature. Because of our research methods, we had to determine the percent water in the entire ears - kernels plus cobs - at harvest, but all water percentages in this paper are in the kernels and are on the wet basis; for example, if corn contains 25% water, 100 lb. of corn consist of 25 lb. of water and 75 lb. of dry matter. (Conversion from percent ear water to percent kernel water was by means of the tables or curves of Miles and Remmenga (1953)).

The general procedure was to plant several varieties of corn in duplicate or in triplicate and to make 6 to 14 periodic harvests from each plot at about 7-day intervals. The ear corn was heat dried to 2 to 10% water before it was shelled. Plantings were made in 11 years, but in 5 years freezes prevented maturity; therefore, data from only 6 years were analyzed. In these 6 years there were 313 plots of corn, 145 variety-years, and 101 different hybrid and open-pollinated varieties. The varieties varied greatly in growth period; the earliest are adapted to northern Wisconsin while the latest one is adapted to low elevations in Tennessee.

Percent Water in Corn at Maturity

The yields from the successive harvests from a plot were related to the percent water in the corn. In order to obtain a reasonably precise trend line, it was necessary to combine data from several varieties and years. To do this well in spite of greatly different

^{1/} Journal Paper No. 986, Purdue University Agricultural Experiment Station.

yields among years and among varieties within years, and in order to avoid fitting a possibly inappropriate form of equation, 2 procedures were used: (1) by linear interpolation between harvests, a yield was calculated for each whole percent water for each plot of corn, and (2) each of these yields was expressed as a percent of the yield with 36% water. It was evident that at 36% water the maximum yield had not been attained. The second procedure resulted in similar percentage yields at any 1 percent water even for varieties which differed 100% in weight of dry matter per acre. The average yield of many plots was then calculated at each whole percent water.

The percent water at the maximum yield was related to the growth period of the varieties. It appeared that the longer the growth period of a variety (that is, the later the variety) the higher was the percent water at the maximum yield. However, detailed study of temperatures and, for each variety, study of the date it reached the maximum yield and how high that yield was led to the conclusion that all varieties appeared to reach their maximum yields with about the same percent water, provided the maximum yield was reached before the weather became cool enough to interfere with normal development of the grain. Accordingly, a new definition of maturity was adopted, namely: corn grain is mature when its dry-matter yield reaches the maximum, provided that maximum is reached before cool weather interferes with normal development. It is my opinion that if corn does not reach its maximum yield before cool weather, it does not really mature, and does not attain its potential maximum yield so far as that potential depends on the fall temperature.

It was not possible to precisely define cool weather which will interfere with normal development because it depends on maximum and minimum temperatures and on the duration of relatively low temperatures. However, it appears that average daily temperatures in the 50's Fahrenheit for 5 to 7 successive days will limit the maximum yield regardless of how warm following days are.

For varieties which reached their maximum yield before cool weather, the maximum was attained in each of the 6 years with 25, 26, or 27% water, and the 6-year weighted average was 26% water. Therefore, I conclude that corn is mature when it reaches 26% kernel moisture, provided it does so before "cool weather". The percent maximum yield was remarkably similar among years. If the yield with 26% water is called 100% yield, the maximum average yield in the 6 years varied from 103.4 to 104.9%, and the 6-year weighted average was 103.8%.

Varieties as late as U. S. 13 reached the maximum yield before cool weather in only 1 of the 6 years. In the other 5 years, the only varieties which matured fully were varieties which are considered very early at Lafayette. Since U. S. 13 is considered well adapted at Lafayette if grown on productive soil, I conclude that what are called adapted varieties seldom mature fully. However, on the average, the "adapted" varieties yield more and are probably more profitable than varieties which are early enough to mature fully in most years. Not only do early and late varieties appear to mature with 26% kernel moisture, but it also seems from our data that varieties in which the percent water declines rapidly after silking and those in which it declines slowly mature with 26% water.

Time from Silking to Maturity

While we were analyzing our data, Shaw (1949), and Shaw and Thom (1951), from Iowa, concluded that corn was mature about 50 days after 75% of the plants were silked, largely regardless of temperature, and that late varieties matured with a higher percent water than early varieties, namely: 42% and 30%, respectively, for the latest and the earliest of Shaw's 3 varieties. We therefore reanalyzed our data and related the yields from successive harvests from a plot to the number of days after 50% of the plants were silked. Our method was similar to that used for moisture, except that we calculated a yield for each plot for each day after silking, and we called the yield at 50 days after silked the 100% yield.

The data in Table 1, column B, lead to the conclusion that the number of days from silking till corn was mature varied from 57 to more than 75. Column C shows that in the various years, the yield increased 1 to 19% after 50 days from silking; and column D indicates that 52 days after silking 87 to 99% of the maximum yield was attained. Fifty-two days after 50% silked is about equal to 50 days after 75% silked, the base used by Shaw.

The variation in the number of days from silking to maturity is due largely to temperature. In 1947, when maturity was reached in 57 days after silking, the average temperature from silking to maturity was 75° F., whereas in 1946, when 75 or more days were required to mature, the temperature averaged only 68, seven degrees lower.

Because of the effect of temperature and because the general trend of temperature is downward with time in the fall, I believe that, in most years, late varieties will require longer to mature after silking than early varieties when all are planted at the same time and under similar conditions. However, it seems likely that a late variety would mature in fewer days after silking than a very early variety in an unusual year in which the temperature was low until the very early variety matured and then became warm and stayed warm until the late variety matured.

Reasons for Differences in Conclusions

Several possible reasons may account for the fact that my conclusions differ from those of other investigators:

1. Others may have had too few data, not enough varieties, replications, and years; and harvests may not have continued long enough.
2. The sample from each harvest may have been too small.
3. No way or only a poor way to combine data for varieties and years.
4. Poor methods of fitting a curve to determine the point of maximum yield.
5. Using untrue assumptions.

Table 1.--Grain yield related to silking^{a/} for varieties which reached maximum yield before cool weather.

Year	Number of days from silking to maximum yield	Maximum yield in percent of the yield 50 days after silking	Percent of maximum yield 52 days after silking ^{b/}
A	B	C	D
1937	78	105	95
1939	58	103	98
1941	60	103	97
1944	68	105	96
1946	75 or more ^{c/}	119	87
1947	57	101	99

a/ Silking date was when 50% of the plants showed silks.

b/ 52 days after 50% silked is about equal to 50 days after 75% silked, the base used by Shaw.

c/ In 1946 the last harvest was made 75 days after silking when, apparently, the yield curve had not yet reached the potential maximum.

6. Unsatisfactory definition of maturity.
7. Failure to use varieties early enough to mature fully.
8. Cool weather or freezes may have come before the corn had reached its potential maximum yield so far as that potential depended on temperature.
9. Influence by previous opinions as to when corn was mature.
10. Fear of stating a lower percent water at maturity than had been published by other researchers.

Trend of Grain Yield

Table 2 shows the trend of grain yield from the time when the kernels contained 40% water until they had dried to 20%. Note that the yield dropped after the maximum was reached. The drop may have been due (1) to respiration of the grain, (2) to development of ear rots, and (3) to actual loss of kernels or ears. The loss of kernels and ears was a minor factor in our work because fallen ears were picked up and yield adjustments were made for ears which had disappeared and for ears partly eaten by animals. On a farm, the decline in harvested yield from the maximum yield grown will undoubtedly be greater than in our experiments.

Effects of Frost

Corn does not seem to attain its potential maximum yield unless it reaches 26% water before cool weather; nevertheless, the yield often increases after cool weather and even after a frost or a freeze which kills some of the leaves. Table 3 shows increases after frost of 3 to 14 bushels per acre. The yield increase after frost is greater (1) the higher the percent water in the corn at the time of the frost, (2) the less the leaf area killed, and (3) the higher the temperature after the frost.

Another observation about the effect of frost is that when ear corn is shelled without drying, the kernel tips seem to break off worse if frost occurs before the corn is fully mature.

Time from Silking to 26% Water

There should be interest in data to help estimate, at silking, when corn will be ready for field shelling. The length of the period from silking till corn is dry enough for field shelling varies with the silking date. Table 4 contains pertinent data for 2 years in which the period varied greatly, and for Ind. 210, a variety which is considered very early at Lafayette. Column D gives the period from silking to 26% kernel water. It should not be inferred that 26% is the proper moisture content when field shelling should begin: I make no recommendation on this point. It is seen

Table 2.--Yield trend of grain which matured before cool weather.

Percent water in kernels	Yield as percent of the maximum yield
40	93.2
38	94.8
36	96.3
34	97.1
32	98.0
30	98.9
28	99.6
26	100.0
24	99.6
22	98.9
20	98.1

Table 3.--Corn-yield increase after a frost or a freeze.

Year	Yield increase after frost, bushels/acre	Percent water in the kernels at frost	Percent of leaf area killed by frost	Temperatures following the frost
1946	14**	48	15	Very warm
1945	6*	54	"Medium"	Cool
1947	5*	48	Less than 5	Moderate
1938	3*	45	"High"	Very warm
1943	3	45	"High"	Warm

** Highly significant: probability less than 1%

* Significant: probability less than 5%

that the period from silking to 26% water increases with later silking within a year. The silking date depends on the date planted, the variety, and the weather -- largely the temperature between planting and silking. For the same silking date in different years, the period from silking to 26% water may vary by more than 2 weeks, although the greatest difference in Table 4 is 12 days.

Lodging Trend in Time

Lodging of corn stalks frequently increases with delay in harvesting. Consequently, later harvesting often results in greater loss of ears and more mechanical trouble. Lodging includes breaking of stalks below the ear and leaning due to weak roots.

Table 5 shows progressive lodging in 4 years for 2 dent-corn hybrids.^{2/} While these 2 varieties are widely grown, they were selected to represent varieties which lodge little (Conn. 870) and varieties which lodge a moderate amount (U. S. 13). Some hybrids lodge considerably more than U.S. 13.

The lodging trend varies greatly among years. Conn. 870 increased little in lodging from mid-October 1951 till mid-February, whereas in 1953 the lodging increased from 5% in mid-November to 74% by mid-December. Because of the difference in trend from year to year, the 4-year average for each variety may not represent any 1 year, but it does show clearly the progressive increase in lodging with time.

Most of the lodging which occurs after October 1 is stalk breaking, which probably results in more loss of ears and in more mechanical trouble than stalk leaning due to weak roots.

Even with the best-standing varieties, delayed harvest often results in a lower harvested yield, but with varieties which lodge worse, the yield loss from delayed harvest may be very great.

Later harvest is accompanied by more dropped ears, but there is comparatively little ear dropping in Indiana, so we have no data about it.

Drying Ears or Shelled Corn

In Indiana we have found the weight of dry matter in shelled corn greater if the ear corn was dried before shelling than if the shelling was done without drying the ear corn. This was true for a range of kernel water before drying of 13 to 33%, which is the entire range of our data. Our ear corn was dried with forced air at 150 to 180° Fahrenheit; the kernels of the corn after drying had 2 to 10% water. Shelling was done with a 1-hole sheller driven by a 3/4-horsepower electric motor. For corn with 13% water in the kernels before drying the weight of dry matter in the kernels_{out} was 2.0% greater for corn shelled after drying than for corn shelled with_{in} drying. For corn with 33% kernel water before drying the weight of dry matter in the kernels was 4.2% greater for corn shelled after drying than for corn shelled without drying.

Table 4.--Effect of silking date on the number of days from silking till corn kernels averaged 26% water; Ind. 210 variety.

Date planted A	Date 50% silked B	Date with 26% kernel water C	Number of days from silking to 26% kernel water D
1944			
May 20	July 21	Sept. 14	55
" 27	" 27	" 29	64
June 5	Aug. 3	Oct. 14	72
" 12	" 9	" 25	77
1945			
May 1	July 26	Oct. 9	75
" 12	" 28	" 12	76
" 24	" 31	" 19	80
June 2	Aug. 5	" 24	80

Table 5.--Trend, in time, of total lodging, 2 varieties in 4 years, 1950-1953.

(Percent)

Date	Conn. 870					U. S. 13				
	'50	'51	'52	'53	Av.	'50	'51	'52	'53	Av.
Sept. 1	2	-	-	-	-	15	-	-	-	-
" 16	-	-	0	0	-	-	-	5	2	-
Oct. 1	9	1	-	-	3	27	4	-	-	10
" 16	15	8	0	-	6	35	8	5	-	14
Nov. 1	20	10	-	5	9	41	9	-	15	18
" 16	23	-	2	5	10	44	-	8	15	20
Dec. 1	23	10	-	-	21	50	20	-	-	38
" 16	-	10	21	74	32	-	21	61	86	55
Jan. 1	-	10	-	-	-	-	23	-	-	-
" 16	-	-	-	-	-	-	-	-	-	-
Feb. 1	-	-	-	-	-	-	-	-	-	-
" 16	-	13	-	-	-	-	45	-	-	-
Mar. 1	-	-	-	-	-	-	-	-	-	-
" 16	-	-	-	-	-	-	-	-	-	-
April 1	40	27	(21)*	(74)*	40	66	75	(61)*	(86)*	72

* Copied from the last previous date; therefore this value may be too small for April 1.

The greater weight of dry matter in the kernels after drying the ears may have 3 causes: (1) Shelling of dried ears was nearly perfect, whereas a few kernels remained on the cobs of ears shelled without drying. The higher the moisture of undried ears, the more kernels remained unshelled. (2) When undried ears were shelled, small portions of the tips of some kernels remained attached to the cob, and the wetter the corn, the greater was this effect. (3) The third possible cause is one which I think is real, although I am not sure. It is my opinion that when corn is being dried, some of the moisture from the cob passes through the kernels. I think the water going from the cob into the kernels carries with it solubles which increase the dry matter of the kernels.

Kempthorne, Schmidt, and Snedecor (1948) reported that 1.1% should be added to the dry matter weight in shelled corn shelled without drying the ears, in order to estimate the weight which would be obtained after furnace drying to 12% water. They attribute this to a bias, which they suggest may have been imperfect shelling of the undried ears. Since the ears were shelled by hand it seems that the bias from imperfect shelling, if any, was very small. Possibly part of the bias may have been due to a real increase in the dry matter weight of the kernels while the ears were drying.

Another investigator, whose report I could not find when I was writing this paper, found that as ears dried, both the weight of nitrogen and its percent in the kernels increased. I do not remember whether the ears were dried naturally or with heated air.

These fragments of information lead me to believe that the dry matter in corn kernels increases during drying of ear corn. Whatever the reason for the increase, it appears that the weight of dry matter in kernels is greater if the ears are shelled after drying rather than before.

Another factor in deciding whether to dry ear corn or shelled corn is the amount of water which must be driven off. The corn cobs contain a great deal of water. Miles and Remmenga (1953) show the relations in the percent water in kernels, cobs, and ears. Some other investigators have published similar data. This information can be used to calculate the amount of water to be removed from shelled corn or from ears to lower the percent water from any value to any other.

Other Bits of Information

The percent water in corn when it is shelled affects the weight of dry matter in the shelled corn. The drier the corn, the more nearly perfect is the shelling. With the good 1-hole sheller which we used, some kernel tips remained on the cobs with water at least as low as 25%, and a few entire kernels remained on the cob tips or butts with water as low as 15%. I am not familiar with the quality of shelling done by field shellers.

When shelling a sample of corn to determine the percent water, it is important to shell the corn in such a way that the entire kernels are obtained. The kernel tip contains a greater percent water than the rest of the kernel. Therefore, if the kernel tips are broken off, the percent water found in the kernels will be biased by being low.

It is sometimes desired to estimate how long corn on standing stalks in the field will require to lose a certain percent of water. Very crude but useful data are these: as an average, corn loses 1% water per day in September, $1\frac{1}{2}\%$ in October, and $1\frac{1}{4}\%$ in November.

Another fact should be called to the attention of persons who dry corn. Many elevators and other buyers pay no premium for unusually dry corn. Therefore, overdrying will often reduce the income from the sale of corn. The upper limit for number 1 corn is 14.0% water. In practice, it is impossible to dry corn to exactly 14.0% water; therefore think of No. 1 corn as having 13.0% water. If corn is sold with 10% water rather than with 13%, the income will be $3\frac{1}{3}\%$ less, when no premium is paid for the drier corn.

Summary

In summary, possible losses and gains from field shelling of corn are listed:

Possible losses from field shelling:

1. Loss from harvesting before the corn has made the maximum yield.
2. The higher the moisture in corn, the greater is the loss due to imperfect shelling.
3. If ears are shelled without drying, there is loss of the increase in the weight of dry matter in kernels, which results while ear corn is dried.
4. Loss of income due to overdrying.

Possible gains from field shelling:

1. Greater harvested yield than from later harvesting, due to less lodging, to less ear dropping, and to other causes.
2. Better quality in early-harvested corn if it is dried rapidly enough.
3. Less water to drive off in drying than if ear corn is dried.
4. Early harvesting often permits gleaning by livestock before much rotting has occurred and while there is less mud than later.

Other points which are stated:

1. Corn reaches maturity when the kernels have about 26% water, provided maturity is attained before cool weather.
2. Corn required 57 to 75 or more days from silking to maturity; the variation is due largely to temperature.
3. The yield declines after maturity.
4. The yield often increases after a frost or a freeze.
5. Within a year, the number of days from silking till the maximum yield is reached is greater for corn which silks later.
6. The drier the corn, the more nearly perfect is shelling.
7. If kernel tips are lost in shelling corn to determine its water content, the percent water is biased downward.
8. In central Indiana, corn on stalks in the field loses about 1% water per day in September, 1/2% in October, and 1/4% in November.

Literature Cited

Kemphorne, O., J. L. Schmidt, and G. W. Snedecor. 1948. The estimation of yield of corn of standard moisture content in hybrid seed corn production. Journal of the American Society of Agronomy, 40: 645-654.

Miles, S. R. and E. E. Remmenga. 1953. Relations of kernel, cob, and ear moisture in dent corn. Purdue University Agricultural Experiment Station, Station Bulletin 599.

Shaw, R. H. 1949. Studies on corn phenology and maturity in Iowa. Ph.D. Thesis, Iowa State College, Ames, Iowa.

Shaw, R. H. and H. C. S. Thom. 1951. On the phenology of field corn, silking to maturity. Agronomy Journal, 43: 541-546.

Discussion

Q. How much increase is there in dry matter between different moisture percentages?

A. Table 2 in the paper gives this information.

Q. Should 26% moisture be recommended as the point at which to begin field shelling?

A. Each farmer should decide for himself when to begin field shelling. With more than 26% water, the full yield has not been made, but after 26% has been reached, the yield begins to fall. Other factors I have named and factors I have not mentioned should also be considered before deciding when to begin field shelling.

- Q. What is the relation between maturity and lodging and dropped ears, that is, gathering losses? If harvesting corn at 30% moisture instead of 26%, what would be gained or lost through failure of corn to develop fully.
- A. I have no data on the relation of percent water to gathering losses. Also see the answers to the two previous questions.

Comment

- (Hukill) There is variation in moisture content among ears in the field. When the average moisture has reached 26%, presumably the ultimate yield has been attained. When the average moisture is 26%, some ears will have 35 to 36% moisture.
- A. Yes, ears vary in moisture. When the average moisture is 26%, an occasional ear may have 40% moisture and an occasional ear may have 15%. As I said, corn on a rather uniform area of soil is mature when the average percent water is 26. Individual ears are mature with a few percent above 26. I have not yet reached a very definite conclusion about the moisture content of individual ears when they are mature.
- Q. How much of the variation in moisture is due to genetic differences and how much to environment such as variation in the field due to high spots and low spots?
- A. I do not know but I think a majority is due to environment.

Abstract of Paper
"Limitations on Drying and Storage Imposed by Growth of Molds"
by

Dr. Clyde M. Christensen
Department of Plant Pathology, University of Minnesota

1. Much deterioration in corn and other stored grains is caused by invasion of the seed by various molds; these are known collectively as "storage molds", and probably 15 to 20 different kinds of them are principally involved in the major types of deterioration.

2. These molds invade seed principally after harvest, not before; this is known to be definitely true in the case of wheat, barley, oats, but some qualifications may be attached in so far as corn is concerned.

3. The major factors that determine the degree to which stored seeds are invaded by the different molds are: (1) Moisture content; (2) Temperature; (3) Time; (4) Degree to which seed is invaded prior to a given storage period; (5) Extent to which grain has been infested by grain insects.

The lower moisture limit of mold invasion for long-time storage of cereal seeds is in the range of 13.0 - 13.5%, wet weight basis. In practice, deterioration caused by molds often occurs at supposedly safe moisture contents because of (a) errors of determination; (b) failure of "average" figures to indicate when some portion of the bulk may have a moisture content in excess of the safe limit; (c) fluctuation and transfer of moisture content from place to place in the bulk; (d) increase of moisture content due to insect development and mold growth.

The lower limit of temperature for the growth of most storage molds is about 40 degrees F. Some of those present in corn may grow slowly down to a temperature of freezing or slightly below. The optimum temperature for growth of most of them is 80 - 90 degrees F.

Moisture content, temperature, and time are all intimately related; thus the lower the moisture and temperature, the longer can grain be stored without damage from molds. The higher the moisture and temperature of the grain, the greater the risk of damage within a given time.

If grain has been moderately invaded by storage molds, then dried to a moisture content below that at which molds can continue to grow, it may continue to deteriorate slowly and discoloration and rancidity of germs may increase.

Presence of certain grain inhabiting insects appears to initiate and to promote the growth of some of the most destructive storage molds even at "average" moisture contents in the grain that should prevent molds from growing.

4. The only practical control now known is to dry the seed to a moisture content that will prevent the growth of molds at the temperatures likely to be encountered in the period of storage, and to keep the moisture contents below the safe limits throughout the bulk and throughout the storage period.

QUALITY REQUIREMENTS OF MARKET CORN

by

Leo E. Holman, Agricultural Engineer
Transportation and Facilities Branch
Agricultural Marketing Service, Marketing Research Division
U. S. Department of Agriculture

Corn as well as other feed grains is marketed principally through livestock and livestock products. However, a considerable amount is sold each year. For example, about 35 percent of the corn harvested for grain in 1953 was sold off the farm. The North Central States produce approximately 75 percent of the feed grains produced in this country. They are especially important as a source of commercial supplies of feed grains, providing about 85 percent of the corn going into commercial channels. An Illinois farmer, for example, sells more than 40 percent of his corn and the Iowa farmer about one-fourth, while a Pennsylvania farmer sells only about 15 percent and the Georgia farmer only 10 percent.

About 54 percent of the corn sold for commercial use goes into livestock feed. One-half of this amount is purchased by feed manufacturers and goes into mixed feed, the other half goes directly to livestock producers. Another 17 percent of the corn sold by farmers is purchased by the wet-processing industry for making starch, sugar and sirup. Another 11 percent is purchased by dry processors for producing corn-meal, hominy grits, flour, and prepared cereals. The remainder of the corn that is sold goes to alcohol plants, into export, and for seed. 1/

In the commercial channels corn and other feed grains are generally bought and sold by grade. Factors that determine Federal grades for grain are test weight, soundness, cleanliness, purity of type, dryness and general condition.

The relative importance of the various grade factors and other quality indexes depends upon the purpose for which the corn is used. The livestock producer purchasing corn for feed is interested in the nutritional value, palatability, soundness, moisture content and storageability of the corn. Some livestock producers have expressed concern over the hardness of corn that has been over-dried with heated air. They feel that livestock do not eat such corn as readily as they do corn having a moisture content of 12 to 13 percent and higher. There should be no such problem where corn is properly dried. Feeding tests have shown that mature corn can be satisfactorily dried at temperatures ranging up to 190° F. without materially affecting its feeding value. Also that "soft" corn, dried at temperatures ranging between 95° F. and 135° F. is about equal to mature corn in feeding value.

The wet-processing industry is interested in the percentages of starch and oil in corn, although starch is its primary object. Corn quality is judged by four characteristics: (1) Contamination by non-corn materials such as cobs, husks, dirt and stones, insect and rodent residues and other foreign materials;

1/ Marketing. The Yearbook of Agriculture - 1954.

(2) moisture content; (3) physical conditions; and (4) chemical composition. Wet millers need an adequate supply of corn in sound physical condition, with low moisture content and free from non-corn material.

Insect and rodent residues have often been a serious contamination problem for wet millers. The increased emphasis on improved sanitation by the grain industry and by public and private agencies should help to solve this problem.

For the wet miller the most serious result of high moisture in corn is the damage that occurs in transit and prolonged storage. High moisture corn also requires the handling of considerably more bushels in order to obtain the same output of finished material. For example, nearly 1/5 more corn must be handled to obtain the same output when corn with 26 percent moisture is milled instead of corn with 13 percent moisture. The additional water introduced into the system with the wet corn also presents a problem.

Corn damaged by heating, souring, molding, and sprouting causes trouble in the wet milling processes and has a detrimental effect on the finished product. There is considerable loss of oil when damaged corn is processed. An increase in fatty acid content of the oil represents an economical loss because the fatty acids must be removed from the oil during processing.

Wet millers have been concerned with another type of damage that results from drying corn at too high a temperature. A relatively small amount of starch that has been heat-damaged will interfere with the normal starch processing operation. MacMaster et al ^{2/} studied the effect of drying conditions upon the composition and suitability for wet milling of artificially dried corn. They report that "final conclusions cannot be drawn from the data at hand. However, the data suggests that temperatures of 150° F. may have an adverse effect upon corn to be used for processing for starch production."

Wet millers are interested in the amino acid composition of the protein fraction as well as the percentage of oil and starch in corn. This is chiefly the concern of the plant breeder, but drying and storage practices may affect these factors.

The dry corn miller does not want corn of mixed colors. The finished product demand is for all white or all yellow. Corn should be sweet and sound and should test 50 pounds per bushel or over. Corn should not contain more than 15 percent moisture and not over 8 percent of small kernels that will pass through an 18/64 round hole perforation. Corn with a high percentage of damaged kernels is objectionable because these kernels are difficult to remove before milling without special cleaning equipment. In studies by Baird, et al ^{3/} they found that "corn dried at temperatures above approximately 130° F. usually gave harder grits and more rubbery germ than that dried at lower temperatures."

^{2/} Studies on the effect of drying conditions upon the composition and suitability for wet milling of artificially dried corn, M. M. MacMaster, F. R. Earle, H. H. Hall, J. H. Ramser, and G. H. Dungan, Cereal Chemistry, Vol. 31, No. 6, November 1954.

^{3/} Studies on a Rapid Test for the Viability of Corn for Industrial Use. Peggy D. Baird, M. M. MacMasters, and C. E. Rist, Cereal Chemistry, Vol. 27, No. 6, November 1950.

With the modern machinery and equipment available for harvesting and drying corn it should be much easier for farmers today to produce corn that will meet the quality requirements of corn marketed for commercial uses.

Often when selling his corn the farmer does not know what the ultimate use of the corn may be. If he knows it is to be used for livestock feed he can use drying air temperatures as high as 175° F. to 190° F. It is doubtful, however, if he would use such high temperatures because of the greater fire hazards involved. If he knows the corn is to be used in making starch he should use drying temperatures that do not exceed 140° to 150° F. It would seem that it would be desirable to use drying temperatures that would not raise the corn temperature above 130° F. to 140° F. Then the corn, if dried to a desired moisture content with an approved drying installation, should be satisfactory for most commercial uses.

Abstract of Paper
"Relationship Between Drying Conditions
and Nutritive Value of Corn"

by

R. E. Davis and C. A. Cabell
Animal and Poultry Husbandry Research Branch
Agricultural Research Service
U. S. Department of Agriculture

The paper reports tests of the effect of various drying conditions and temperatures on the total energy value, protein nutritive value, and vitamin content of corn. The samples tested included mature corn of 15 to 31% moisture content and soft, immature corn of 42 to 60% moisture content.

Effect of drying air temperature on energy value. The energy value of the corn was determined in feeding tests with weanling rats and swine. No significant differences were found in the energy value of mature and immature corn heated to various temperatures up to 190° F.

The effect of drying air temperature on protein nutritive value was determined in feeding tests with weanling rats. Figure 1 shows the effect of various drying conditions on mature corn of 22% moisture content grown at Beltsville, Maryland. No significant difference in the protein nutritive value resulted from drying this corn at temperatures up to 190° F.

Figure 2 shows the effect of various drying conditions on the protein nutritive value of mature corn of 31% moisture content grown in Illinois. The samples dried at 173° F. and 116° F were taken near the hot inlet, thus the temperature of the corn was very nearly the same as that of the drying air. There is evidence of damage to the protein nutritive value of the sample dried at 173° F. since all of the corn dried at lower temperatures gave significantly better rat growth. The high protein nutritive value obtained at 116° F. suggests the need for further investigation at temperatures between 116° and 173° F. 1/

Figure 3 shows the effect of various drying conditions on soft, immature corn of 42% moisture content. The corn was from the same field at Beltsville, Maryland as that used in the tests reported in Figure 1. While this corn was much wetter than could normally be shelled, it illustrates a situation that could occur in a "soft-corn year". The best result was obtained with forced air drying at 95° and the greatest damage at 190°, the highest temperature of the test. Comparison of Figures 1, 2 and 3 suggests that the higher the moisture content of the corn at time of drying, the more easily the protein nutritive value may be damaged by high temperatures. The low value of the wet corn dried at room temperature may be due to enzymatic changes.

1/ The higher protein nutritive values obtained with the Illinois corn are believed due to soil, seasonal or other factors and not to the particular drying temperatures used.

Effect of drying air temperatures on vitamins. No significant loss of vitamins was found in either mature or soft corn heated to various temperatures up to 190° F., but heating to 300° F. caused small losses of thiamin and carotene in both mature and immature corn.

Need for further study. Because of the limited scope of this study, no firm conclusions can be drawn. Further investigation should be made of the effect of drying temperature on the protein nutritive value of corn, particularly in the field-shelling range of 20 to 30% moisture content.

Discussion

Several questions were asked as to whether the temperatures stated were air temperatures or corn temperatures during drying. The text has been revised in an attempt to clear up these points. All temperatures on charts except Figure 3 were taken with thermometers at the outlet of air into corn.

* * * * *

Q. Could you name any critical temperature of air for mature corn?

A. I don't believe I could give a critical temperature.

Q. If this corn were normally supplemented with a protein which would supply the lysine and tryptophane, would you expect from your data that you would get any depression even if soft corn were heated up to 200°?

A. Yes, I believe there would be a depression in growth even after addition of lysine and tryptophane.

Q. What was air volume per bushel used with these temperatures you quoted?

A. Sorry, I can't give you those.

Comment by Ashby: The air volume used with the Beltsville corn was rather high. There were only 200 or 300 bushels in the crib and the air passed through swiftly.

Q. Was 135° as high as you would recommend for drying soft corn?

A. That is our conclusion relative to wet corn heated under the conditions we used.

Q. If corn was 20 to 30% moisture what would be highest temperature you would recommend?

A. If you are going to limit the moisture to that I could not answer. Would have to limit this recommendation to 30 to 35% corn.

Q. With use of 190° heat on mature corn, did you get any protein nutritive damage?

A. There was no damage to field-dry corn.

Q. Have any tests been made where grain temperature was taken as grain was being dried?

A. The temperatures shown in Figure 3 are substantially the grain temperatures.

Q. Was there no effect on vitamin content from drying?

A. Small losses are indicated in carotene and thiamin as shown in Table 3.

The following comments were submitted by W. V. Hukill following the meeting:

"The question of temperature during drying came in for some discussion at the conference. Most of the data available is on drying air temperature, not grain temperature. There was some discussion of the desirability of stating the grain temperature instead of the air temperature. It seems to me that until we get farther along than we are now, results related to drying air temperature are more pertinent than if they were related to grain temperature. For practical purposes no one can describe any given operation in terms of grain temperature, but it is fairly easy to know or control the entering air temperature.

It is probably true that damage, if any, is related to grain temperature but from what is known now it doesn't seem likely that quoting estimated grain temperatures would be very useful. Are we concerned with temperature at the surface, at the center, or at the germ? No doubt the temperature effect is closely related to moisture content at the time of exposure to high temperature. A statement of grain temperature without duration of exposure and moisture content at time of exposure wouldn't be very useful.

I think the important thing about the data available is the entering air temperature. Studies in which the moisture and temperature history were examined should be made, but it seems questionable if the data from Davis and Cabell can be extended to show the combined effects of grain temperature, time and moisture content."

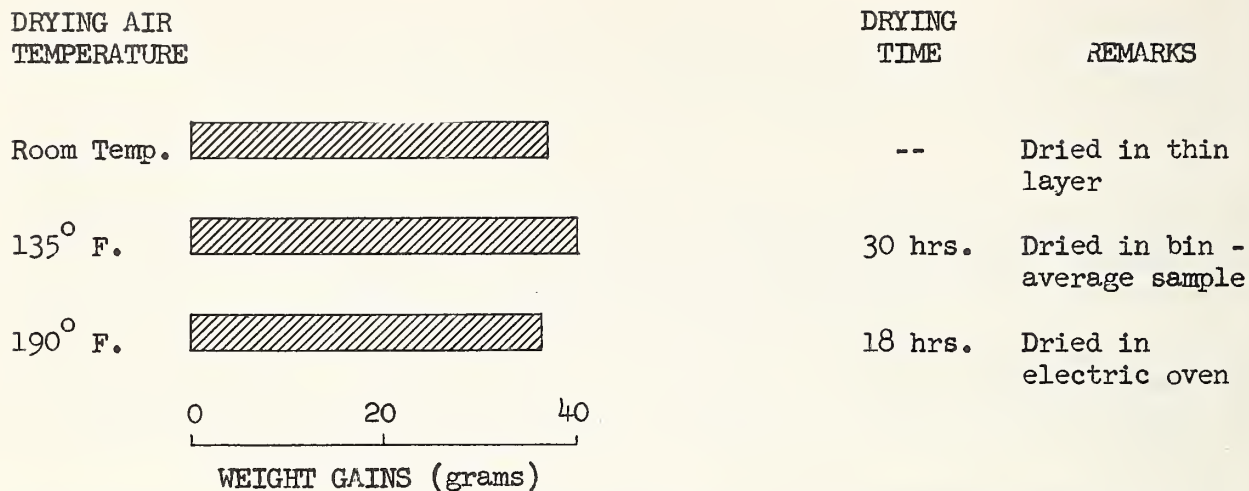


Figure 1.--Effect of Drying Air Temperature on the Protein Nutritive Value of Mature Corn of 22% Initial Moisture Content as Measured by Weight Gains of Weanling Rats.

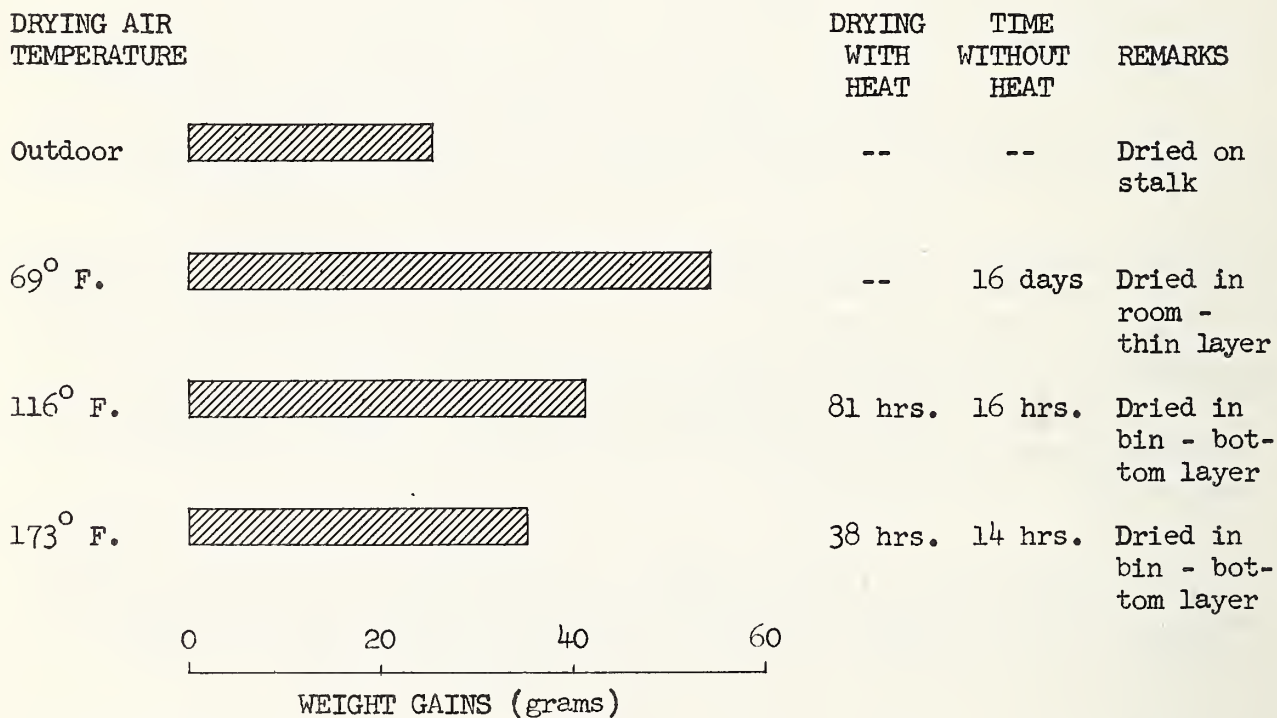


Figure 2.--Effect of Drying Air Temperature on the Protein Nutritive Value of Mature Corn of 31% Initial Moisture Content as Measured by Weight Gains of Weanling Rats.

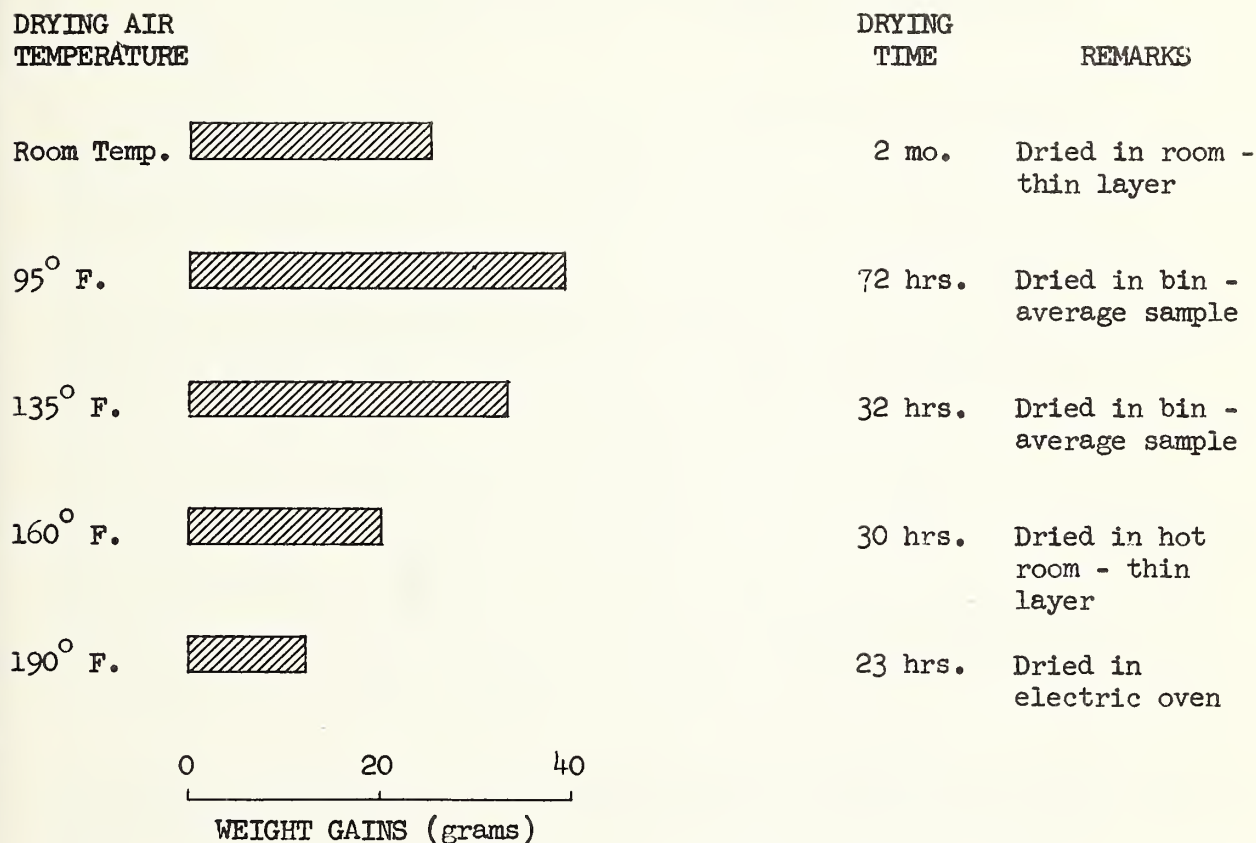
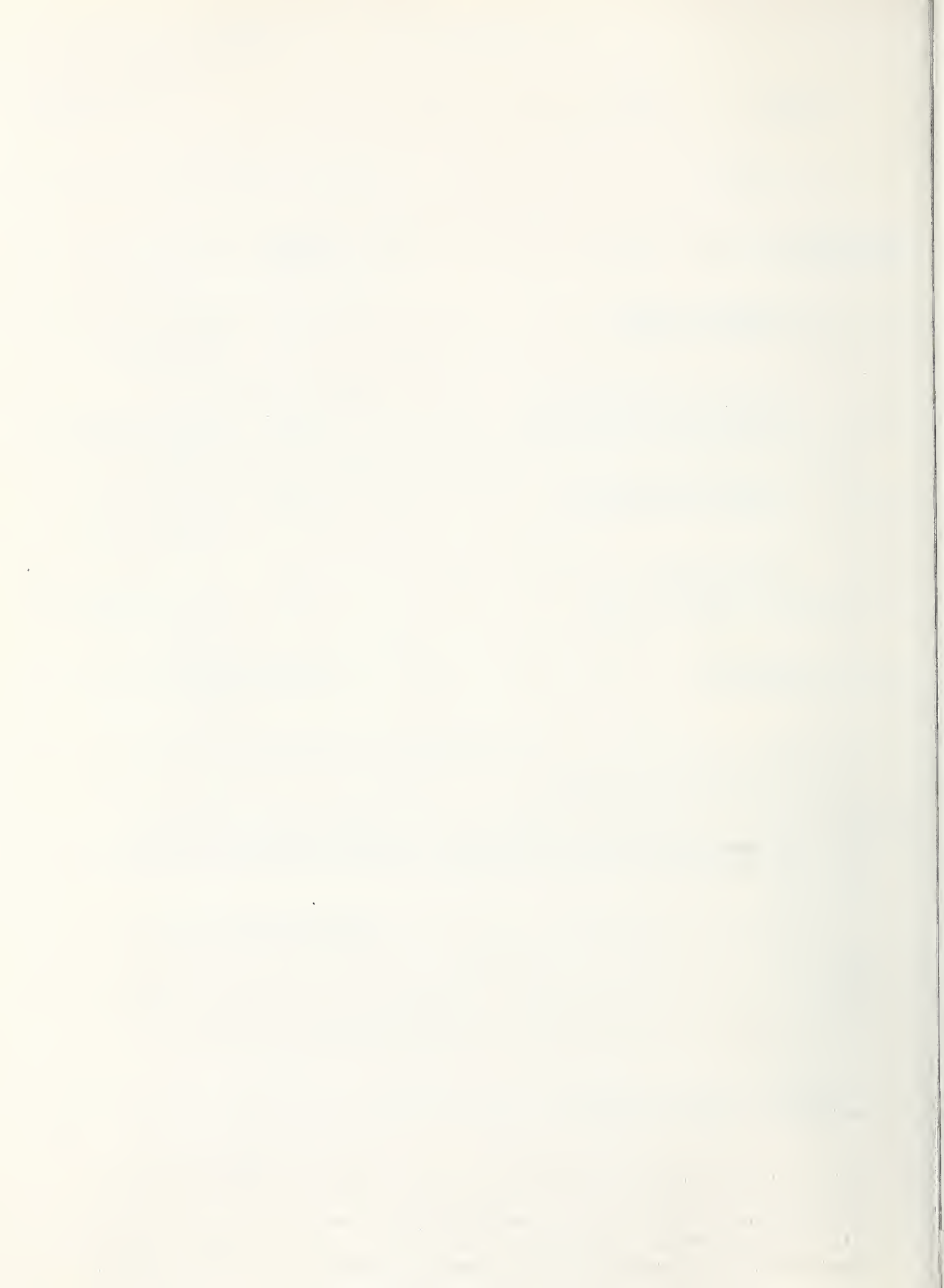


Figure 3.--Effect of Drying Air Temperature on Protein Nutritive Value of Soft (Immature) Corn of 42% Initial Moisture Content as Measured by Weight Gains of Weanling Rats.



PRINCIPLES OF DRYING

by

W. V. Hukill

Agricultural Engineering Research Branch
Agricultural Research Service, U. S. Dept. of Agriculture

In discussing limitations in the practical problem of drying shelled corn it is of interest to examine some of the physical or engineering limitations that arise from the drying process. Among the questions that are asked whenever a drying system is being considered are: How many bushels per hour can be dried? How many cubic feet per minute of air will it take? How much air pressure is needed? How much fuel or power or both will it take? These and many other similar questions have to be answered for every drying installation. The limitation implied by each of these questions has a direct bearing on the best choice of a system for any given situation. Some of these limitations are set by the character of the grain, the use to be made of it, the method of harvesting, the buildings and handling equipment available, the amount of attention the operator is able or willing to supply and the climate. Each of them depends partly on the nature of the drying process. While a complete understanding of the drying process would not by itself enable one to lay out a satisfactory drying system, still no drying system can perform without conforming to certain principles of operation, either by accident or by deliberate design. Fortunately some of these principles are known and can be used to guide design and operation of drying equipment.

Since it is not possible to review here all elements of the principles of grain drying, this discussion will be limited to a few phases of drier design: (1) The function of air in drying and the relation of the psychrometric chart to the drying process; (2) Power requirements for drying; (3) The pattern of moisture changes that occur in a drying bin; and (4) The relation of air distribution within the grain to effective use of the drying air.

In order to emphasize the predominating relations it will be necessary to neglect many secondary variations. For example, the heat of vaporization of water will be considered to be 1060 B.t.u. per pound. Actually it varies with temperature and pressure and even with the grain moisture content. For practical purposes however it is close enough to 1060 B.t.u. per pound throughout the range of ordinary drier operation to justify using the constant value in this discussion.

The Function of Air in Drying

All common types of grain driers use air circulation through the grain. The air serves two purposes: (1) to carry away evaporated moisture, and (2) to supply heat for evaporation. Of these, the first is relatively unimportant in the sense that it does not limit the performance of the ordinary drier. The second function of the air, to supply heat for evaporation, is the one with which we must be concerned. This is equally

true of heated air or unheated air driers. It is a common observation that air leaving a drier is cooler than that entering. It is less common to interpret the temperature drop in the air as a direct measure of the amount of drying accomplished. This interpretation, however, is sound and affords a rather simple way of estimating the capacity of a drying system. (Here again a secondary effect, the initial temperature of the grain, is neglected since for most cases its influence on the result is very small.)

When air with drying capacity passes through damp grain water evaporates. The evaporation cools the grain and air. As a result the capacity of the air for picking up more moisture diminishes in two ways. First the moisture content of the air is higher, and second, the temperature, and therefore the total moisture-holding capacity of the air, is lower. The temperature drop and the moisture increase in the air take place simultaneously and may continue until the air is saturated. Throughout the time when this is going on the amount of water evaporated at any time is proportional to the temperature drop at the same time. No evaporation can occur without a simultaneous temperature drop. Since it takes about 1060 B.t.u. to evaporate a pound of water, the evaporation of each pound of water must be accompanied by a drop in air temperature sufficient to release 1060 B.t.u. This might take place in 1000 pounds of air dropping 4.4°F or 100 pounds dropping 44°F for example (the specific heat of air is approximately 0.24 B.t.u. per pound

$$\frac{1060}{1000 \times .24} = 4.4).$$

This process is conveniently represented on the psychrometric chart.

A skeleton psychrometric chart is shown in Figure 1. It is laid out with temperature in degrees Fahrenheit across the bottom and moisture content in pounds of water per pound of air along the side. The saturation line shows the maximum amount of water vapor that can be present at any temperature. Any point on the chart to the right of and below the saturation line represents some condition of air with respect to temperature and moisture content. Other properties are usually shown by other lines on the chart as well, for example, relative humidity, specific volume, or wet bulb temperature. For our purpose the wet bulb lines are most important. Consider a condition of air to be used for drying, for example 80°F and 0.05 pounds of water per pound of air. This is represented by point A on the chart. When the air enters the grain, the air condition starts to change, tending to move upward on the chart as moisture leaves the grain and also tending to move to the left as the temperature drops. A point representing the new condition of the air would be above and to the left of A. Since the temperature drop is proportional to the amount of water evaporated, a point representing the changing condition of the air moves upward and to the left along a straight line. If the air stays long enough in the grain it will eventually reach equilibrium with the grain and will be represented on the chart by some point F on this straight line. For very damp grain point F will be at the intersection of the straight line and the saturation line, point I.

This representation provides a convenient way of determining how much drying can be expected of air of a given condition, particularly so since the straight line representing the changing condition of the air is almost identical with a wet bulb line on the psychrometric chart. For practical purposes it may be considered to be identical. In other words, as air moves through the grain its temperature drops but the wet bulb reading remains constant. This relation permits direct reading from the chart of the maximum amount of moisture that can be removed by each pound of air. In the case shown on the chart, the air starting at 80°F can cool to a minimum of 57.5°F, a drop of 22.5°F, and the moisture content can increase to about 0.01 pounds of water per pound of air. Each pound may pick up about .005 pounds of air. This procedure on the psychrometric chart will show the maximum amount of water that can be evaporated by each pound of air. This procedure can be simplified and the computation made without reference to the psychrometric chart if the initial dry bulb temperature and wet bulb temperature are known. The difference between the two is a direct measure of the drying potential of the air. For each degree difference, each pound of air can evaporate about .00023 pound of water. A convenient number to use is 1400. This is the number of pounds of air required to evaporate one pound of water if the air temperature drops one degree. If the air is saturated when exhausted from the grain, the amount of air required for each pound of water evaporated is

$$\frac{1400}{T_d - T_w}$$

where $T_d - T_w$ is the wet bulb depression or the dry bulb minus the wet bulb of the entering air.

The first step in laying out a drying bin is to estimate the total number of pounds of water that must be evaporated. Table 1 shows the amount of water in each bushel of several grains at various moisture contents. This estimate together with an estimate of the wet bulb depression of air available for drying permits computation of the total amount of air required to complete drying. The same procedure applies to heated or unheated air, and shows the minimum total air requirement. The actual air requirement will exceed this estimate if the grain has less than about 25 percent moisture or if the air is passed too quickly through the grain. With the volumes of air (cfm per bushel) usually used in unheated air drying the actual air requirement is not much more than the computed minimum. With heated air drying it is customary to use large enough air volumes that the air is exhausted from the grain before the full temperature drop in the air is achieved.

In heated air drying an estimate by the above method will show the minimum air requirement. One of the principal problems in design is to approach as nearly as possible the complete use of the available heat in the air and at the same time to keep the size of the drying bin as small as possible. These requirements necessarily oppose each other and the compromise results in using something less than the full amount of available heat. USDA Leaflet 331 shows some examples of bin sizes and rates of air flow within a practical operating range. Even though a drying bin does not utilize all the heat available in the air it is useful to know how much is available. It is also useful to know what fraction of the

Table 1. Pounds of water per bushel¹ of grain at different moisture content percentages²

Grain moisture content (percent)	Amount of water per bushel of		
	Shelled corn and grain sorghum (Lbs dry matter/bu = 47.32)	Wheat and soybeans (Lbs dry matter/bu = 51.6)	Oats (Lbs dry matter/bu = 27.4)
	Pounds	Pounds	Pounds
35	25.4	27.8	14.6
30	20.2	22.1	11.7
28	18.4	20.1	10.6
26	16.6	18.2	9.6
24	14.9	16.4	8.6
22	13.3	14.6	7.7
20	11.8	12.9	6.8
18	10.4	11.4	6.0
16	9.0	9.8	5.2
14	7.7	8.4	4.4
12	6.5	7.0	3.7
10	5.3	5.8	3.0
8	4.1	4.5	2.3

¹A bushel is defined here as the amount of grain required to yield 56 pounds of shelled corn or grain sorghum at 15.5 percent moisture, 60 pounds of wheat or soybeans at 14 percent, and 32 pounds of oats at 14.5 percent.

²To determine the number of pounds of grain required to make a bushel at a given moisture percentage, add the pounds of water to the pounds of dry matter (shown at head of column). For example: To obtain the weight of corn at 28 percent moisture content to make a bushel, add the pounds of water (18.4) to the pounds of dry matter per bushel (47.32). This totals 65.7 pounds. It requires 65.7 pounds of corn of 28 percent moisture content to make a bushel (56 pounds) of 15.5 percent corn.

heat supplied is available for drying. This can be taken from the psychrometric chart also. When atmospheric air is heated, then passed through wet grain, the process is followed on the psychrometric chart by first locating the point representing the atmospheric air condition, for example point O on Figure 1; second, following a line horizontally to the right to a point representing the condition of the air after heating, point A; and finally moving upward to the left along the wet bulb line to the final condition of the air after exhausting from the grain. If the air exhausts saturated its final condition is at the intersection of the wet bulb line and the saturation line. In this case the thermal efficiency or the ratio of heat used for evaporation to that supplied by the heater is the wet bulb depression of the heated air divided by the rise in temperature of the air during heating. This ratio is the maximum portion of the heat supply that can be used in evaporation. It is usually less than 100 percent but under some conditions may be greater than 100 percent.

Power Requirements

One of the other limitations in design is the necessity for keeping the power requirement within reason. The depth to which grain can be piled is limited only by the increasing pressure and therefore increasing power requirement with greater depths. As far as the drying process itself is concerned, there is no depth limit for successful drying. Grain of any depth may be dried equally well if the air volume per bushel is maintained at a satisfactory level. However the power requirement increases rapidly as the depth increases so it is necessary for economy to use a limited depth. Data on the resistance of various grains to air flow has been published by Shedd. With this data it is possible to compute the pressure required to supply given air flows to any depth of various grains. For preliminary estimates of power requirement it is convenient to remember that with any fan operating at a reasonable efficiency each horsepower is capable of moving 3000 to 4000 cfm against a pressure of one inch, water gage. Thus a fairly accurate estimate of power requirement can be made by applying the rule

$$\text{H.P.} = \frac{\text{cfm} \times \text{inches pressure}}{3000}$$

After the design is completed it is necessary to verify or correct this estimate by reference to the performance chart of the particular fan selected.

Shedd's data on pressure requirements are for the case in which the air is moving in straight, parallel lines through the grain, as for example in a straight side wall bin with a false perforated floor. If floor ducts are used or other arrangement that results in curved or divergent flow lines, then the pressure required for a given flow is increased. Tests have been made and others are under way to define the effects of divergence of flow lines on air pressure but so far no generally acceptable formulas have been presented for predicting pressure requirements without depending on the judgment of the computer.

Pattern of Moisture Changes

When grain in a bin is dried, that next to the air intake dries first. That further along in the air stream may not start to dry at all until ventilation has continued for some time. After drying has been in progress long enough, the grain nearest the intake has completed drying, that further along the air path is losing moisture, and further yet is a portion of the grain that has not started to dry. The portion in which drying is actually taking place might be called the drying zone. With high rates of air flow the drying zone may include all the grain in the bin. With low rates of flow, the zone may be very shallow, most of the grain at any time being above or below the drying zone. In either case the zone advances through the grain, moving forward along the air flow lines. When the air moves in parallel lines through the grain, the drying zone moves forward as a uniformly advancing front, the rate of movement of the front being directly proportional to the velocity of the air. The time required for the drying front to reach any given level is directly proportional to the time required for the air to traverse the grain to that level. In a bin with parallel air flow the air traverse time can be converted to cfm per bushel and it is customary to describe the rate of flow through the grain in cfm per bushel. For many purposes this is most convenient but the flow can be described equally well in terms of traverse time. For example, air flowing through grain at the rate of 3 cfm per bushel stays in the grain for 10 seconds; at 1 cfm it stays in the grain for 30 seconds. This is for a grain which has 40 percent void space between the kernels. For some purposes, particularly when the air flow lines are not uniform, it is convenient to express the rate of air flow in seconds of traverse time instead of in cfm per bushel.

When the air flow along different paths is not uniform the drying front advances, not as a flat plane, but with some points advanced and some retarded. All points on the drying front are points of equal traverse time. We are usually concerned with the time required for the drying front to reach the top surface of the grain. If the front is not uniform then we are concerned with the time required for the most retarded part of it to reach the surface. If for example the grain moisture and the conditions of the drying air are such that a minimum of 3 cfm per bushel is required for satisfactory drying, then the most retarded part of the drying front must have a traverse time at the surface of the grain equivalent to 3 cfm per bushel or 10 seconds. In other words, if the air stays in the grain for 10 seconds in the poorest ventilated region, then the requirement of 3 cfm per bushel is met.

Air Distribution within the Grain

Since the time required to dry at any point depends directly on how long it takes air to reach that point, it is of interest to observe how fast air moves along various flow lines in a typical bin. Figure 2 is a photograph of a model bin in which air is exhausted at the lower right-hand corner. Smoke has been injected at various points and the light

lines show the paths of air flow. Those on the right are nearly straight and those to the left are increasingly curved. The time required for air to traverse the curved flow lines is much greater than for the straight lines, more difference than the relative lengths of the flow lines. The traverse time along any flow line can be computed. From such computation an estimate can be made of the relative progress of the drying zone along the several flow lines. If the air along one of the curved flow lines takes twice as long to move through the grain as along a straight path then the drying equipment will have to be operated twice as long to complete drying at the end of the curved path. This effect is reflected of course in the cost of the drying operation.

Curved flow lines appear whenever air is admitted or exhausted from more than one surface, or when multiple ducts are used instead of a continuous perforated floor. The effect of such curved flow lines is illustrated in Figure 3 which shows a cross section of a full scale bin in which shelled corn was dried. The wall to the right, against which the grain rested, was covered with flyscreen and that to the left was of sheet metal with openings every two feet. For reasons related to the tests the air was drawn out of the central tunnel instead of being forced into it but the effects are similar for either direction of air flow. Moisture sensitive elements were buried in the grain and readings of moisture were made periodically. The dots in the figure show the locations of sensing elements. Readings from the elements showed when the drying zone had passed each point. The lines on the chart have been drawn to connect points of equal drying time. Those on the right are relatively straight, the drying zone progressing from the screened wall toward the tunnel in a relatively uniform front. Those on the left show how the drying time was influenced by the spaced air entries. Opposite each opening in the wall there is a flow line along which the drying progressed about like it did on the right side, but opposite each wall sheet between openings there are flow lines along which the drying was retarded by several days. Further studies are under way on more typical duct arrangements for the purpose of getting better estimates of the effect of duct spacing on increased drying time.

Economic design of a drying system requires choice of balances between pairs of conflicting objectives. For example, uniformity of final moisture content tends to improve with greater air volumes, but at the same time greater air volumes tend to reduce the amount of moisture picked up by each pound of air; shallower depths of grain tend to reduce the cost of the bin; use of spaced ducts rather than a full false floor reduces the installation cost but increases the power and air volume requirement. Judgment is required in choosing suitable compromises. Some of the decisions can be facilitated by least-cost computations if the underlying principles are understood.

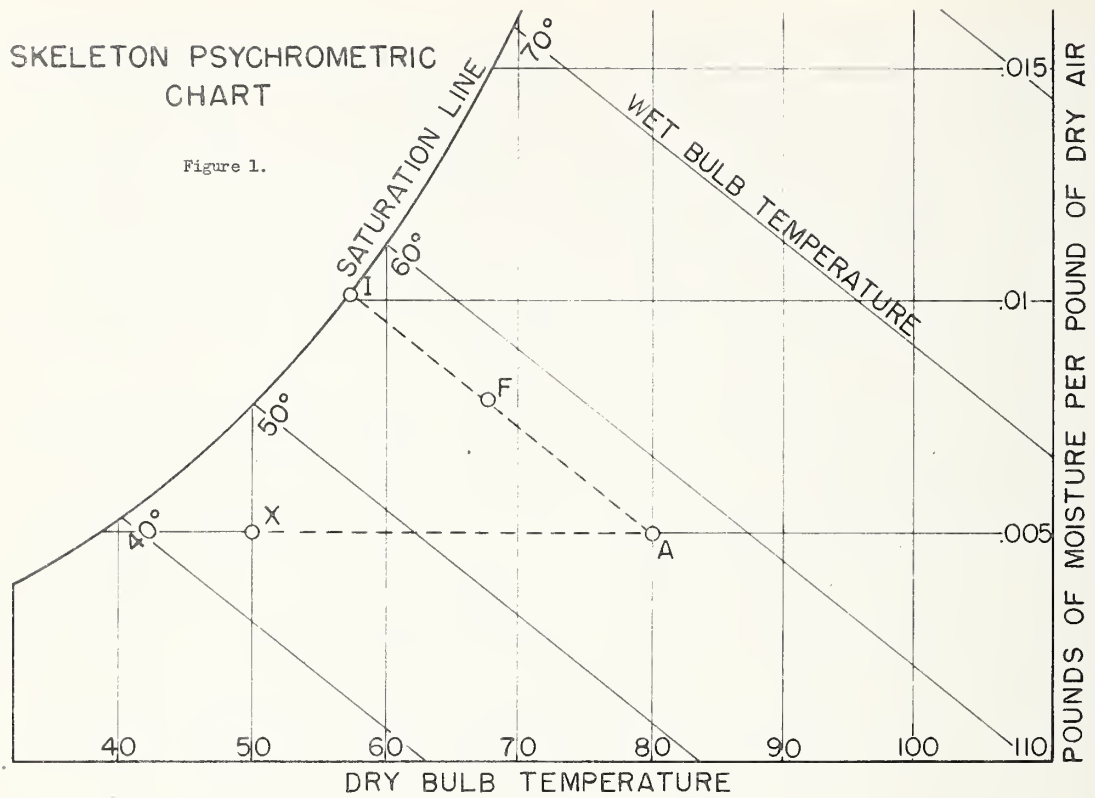


Figure 1.--Skeleton psychrometric chart.

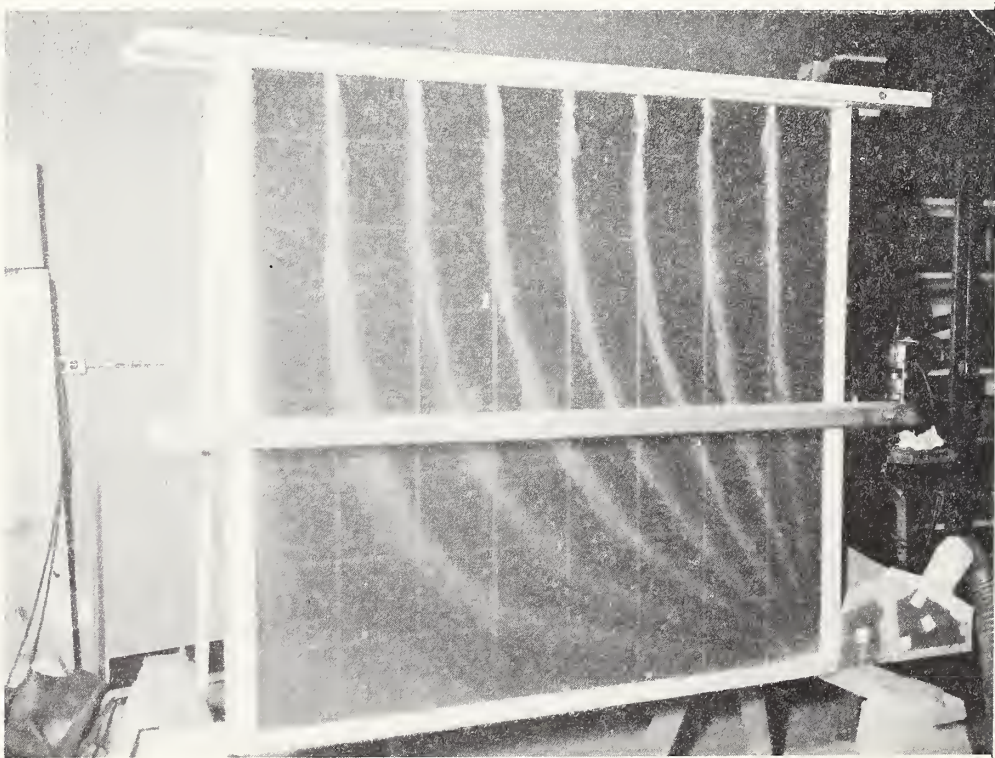


Figure 2.--Smoke patterns indicate the lines of air flow in a model bin having a glass face.

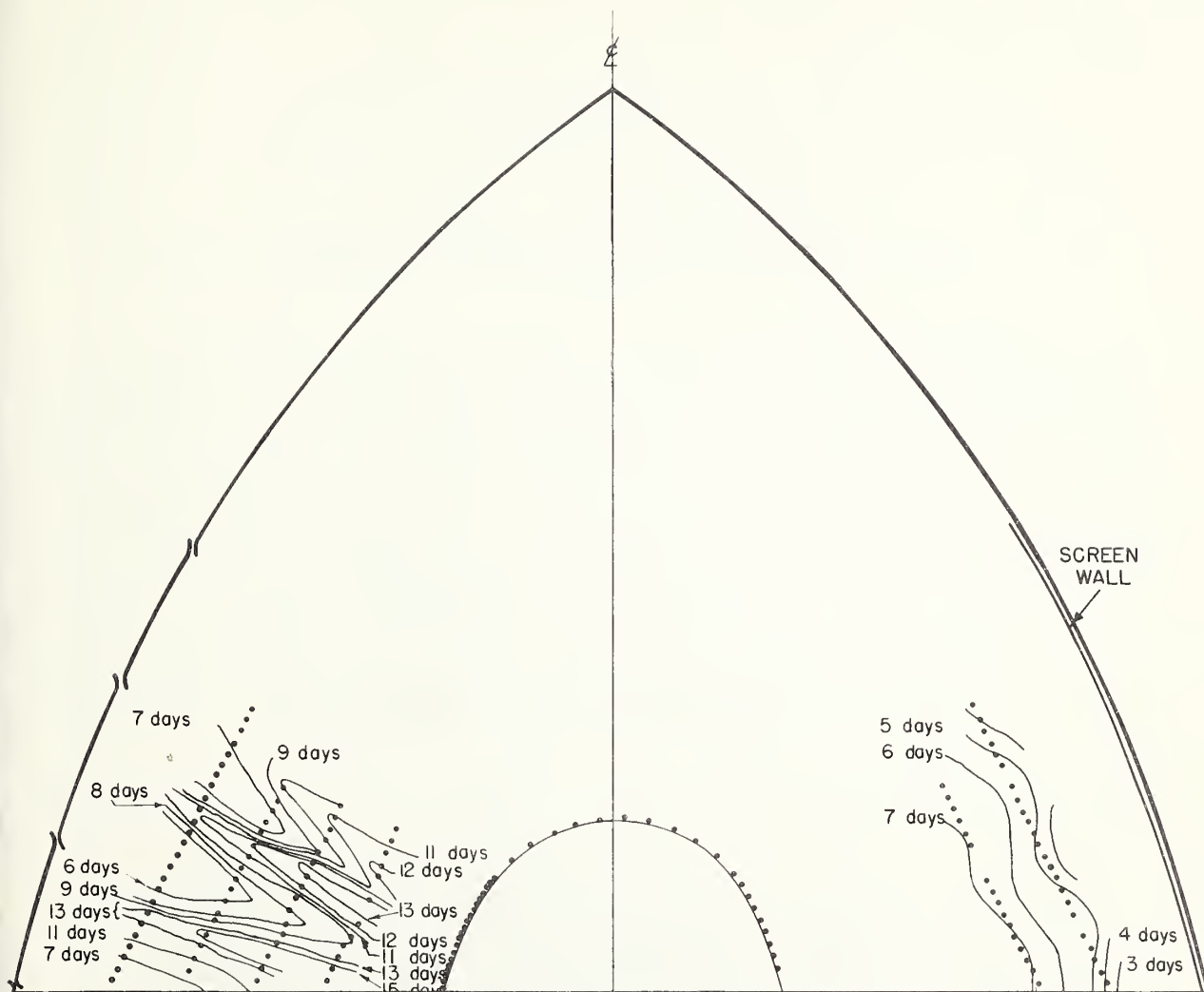
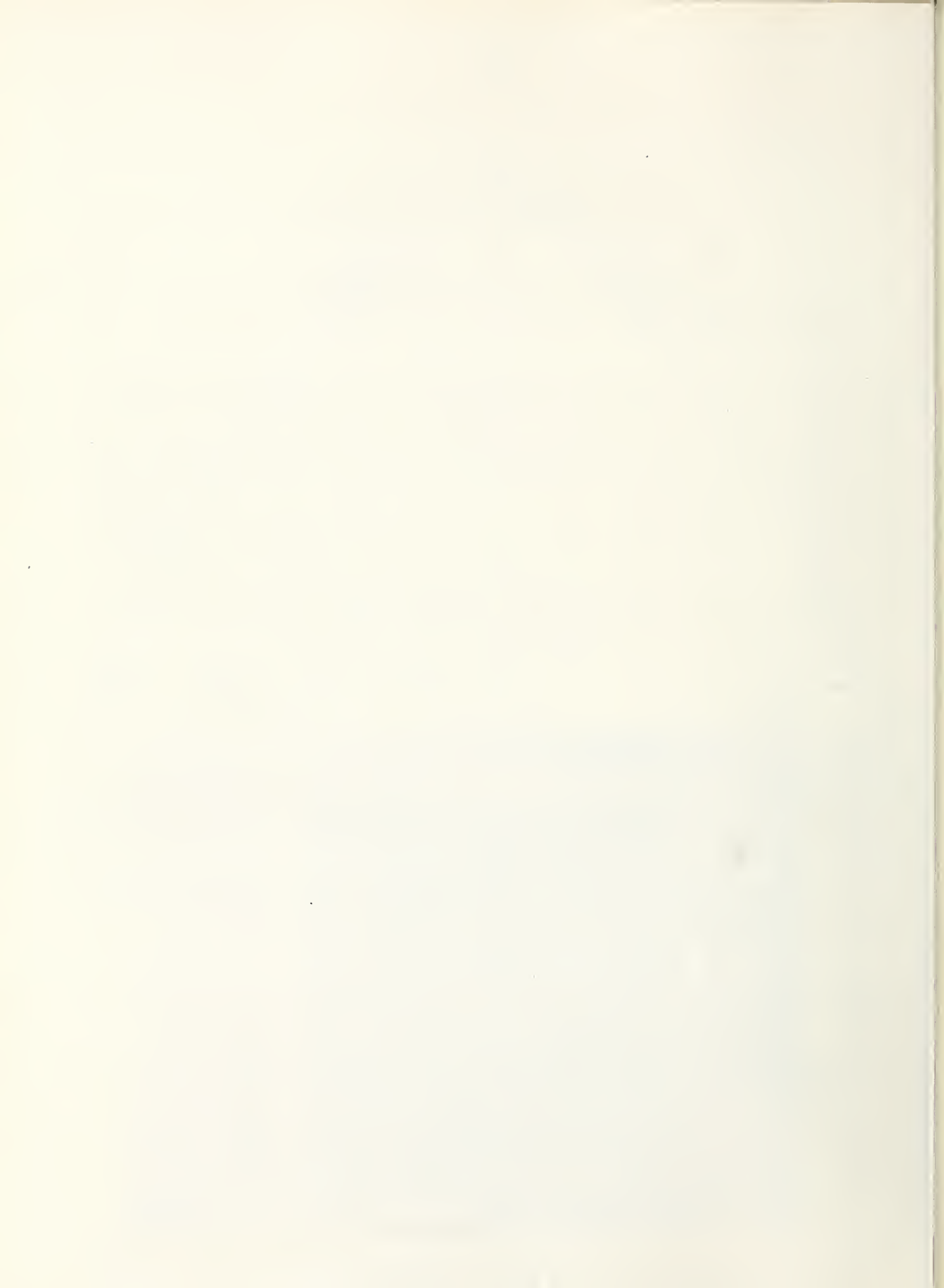


Figure 3.--Lines of equal moisture content in a grain bin. Lines at the left are distorted because air is permitted to enter the grain at only a few points.



UNHEATED AIR DRYING-IN-STORAGE 1/

by

G. M. Petersen, Assistant Professor,
Agricultural Engineering Department,
University of Nebraska, Lincoln, Nebraska
and

J. W. Simons, Agricultural Engineer
Agricultural Engineering Research Branch,
Agricultural Research Service, U. S. Department of Agriculture

The title assigned to this discussion is somewhat redundant when the drying of shelled corn is the primary consideration. Drying with unheated air is virtually synonymous with drying in storage, so far as shelled corn is concerned. Drying with unheated air is a rather slow process and if any appreciable quantity of grain is to be dried during a single harvest season, the drying unit must handle rather large volumes of grain at one time. The most logical method of obtaining the necessary volume is by adapting the storage bin as a part of the drying system. When the grain is dried in the storage bin, unheated air has generally proven to be the most satisfactory drying medium, except that in some cases it may be desirable to use supplemental heat. (Supplemental heat is intended to reduce the relative humidity of the drying air to values favorable to drying, rather than to heat the air to some predetermined temperature, as is the case in heated air drying.)

Four primary questions are commonly raised whenever it is proposed that unheated air should be used to dry grain in storage. These questions are:

When is it necessary to dry grain after harvest?

Can grain be dried satisfactorily by forced circulation of unheated air, particularly shelled corn which must be dried during the fall?

What is the recommended procedure for drying grain with unheated air?

What alteration or adaptation of storage structures is necessary if grain is to be dried in storage?

There is no one specific answer to any of these questions. However, the following discussion is intended to provide a basis for answering the questions for any given case.

Grain should be dried after harvest whenever the grain is to be stored, if the grain moisture content is above the moisture content conducive to safe storage. Corn shelled at harvest time will almost always require drying after harvest if it is to be stored. It is usually impractical to dry corn in the field to less than 15 percent moisture content, and harvest at 20 percent or higher moisture contents will likely be necessary to minimize field and harvest losses. For safe storage of shelled corn in conventional bins, the grain moisture content should never be above 15 percent and generally a moisture content of 13 percent or lower is necessary. In northern states, shelled corn can usually be satisfactorily preserved during winter storage at moisture contents of 14 to 15 percent, if the grain is properly cooled when put into storage. For summer storage in northern states, and for any

1/ Published with the approval of the Director as Paper No. 778, Journal Series, Nebraska Agricultural Experiment Station.

storage in southern states, the corn will need be dryer. The Agricultural Stabilization and Conservation Service (formerly Production and Marketing Administration) has been accepting for storage shelled corn with up to 13.5 percent moisture content. Most research workers recommend that shelled corn have not over 13 percent moisture content for storage periods of one year or more. Indicative of recommendations for northern states, Nebraska recommends that shelled corn to be stored through the summer should contain not over 13 percent moisture, with 12 percent to be preferred for storage periods of more than one year duration. As for southern states, Georgia's recommendations for maximum moisture content stored shelled corn are 12 percent in inland foothill or mountainous regions and 11 percent in coastal plain areas.

The principal problem in drying shelled corn with unheated air is to reduce the grain to safe moisture contents before significant deterioration occurs. Foster (1), reporting on tests in Indiana, found an allowable drying period of about 2 weeks for wheat and 4 weeks for shelled corn, to dry the grain to 15 percent moisture content provided there was always sufficient air circulation to keep the grain cool and that drying was continued beyond this specified period until the desired final moisture content was attained. It seems probable that the difference in drying period for wheat and corn is primarily a difference in the ambient air conditions at the different harvest seasons rather than a difference in the two grains. Assuming this is true, and considering the results of various drying experiments, it appears that a reasonable period for drying shelled corn to not over 15 percent moisture content would range from about 2 weeks in southern states to about 4 weeks in northern states. If drying is then continued until safe storage moisture contents are attained, and if the corn is kept cool throughout the drying period, there should be virtually no decrease in viability or market grade of the corn, and very little increase in fat acidity. (Fat acidity below 22 units per 100 grams dry matter is indicative of sound corn.)

Successful drying of shelled corn with unheated air will of course be dependent upon ambient weather conditions, but should be possible in almost any section of United States. Hukill (2) has discussed the basic principles of grain drying. Simply stated, drying will occur whenever air is circulated through grain if the grain moisture content is higher than the moisture content which would be in equilibrium with the air temperature and relative humidity. The equilibrium relationships between the kernel moisture in corn and the temperature and relative humidity in air are shown in Figure 1. It is evident from this chart that a relative humidity of 70 percent should dry shelled corn to the 15 percent moisture content necessary within a limited period, although lower relative humidities would be necessary to complete the drying. As an indication that the needed 70 percent relative humidity can reasonably be expected in most areas, Figure 2, shows temperature and relative humidity data for three states superimposed on the equilibrium chart of Figure 1. The eastern Virginia and the Georgia areas should be a reasonable indication of conditions where least favorable weather for unheated air drying would be expected, yet the mean relative humidity in these areas is but little above 70 percent during September and October. Nebraska would be expected to be one of the dryer states of the corn producing area, but even here the mean relative humidity is apparently about 66 to 68 percent during the corn harvest season. The data in Figure 2 would indicate that little differences in drying rate might be expected in the states for which data are shown, since mean relative humidities are quite near the same. Actually, mean relative humidities are only one indication of possibilities for drying with unheated air. Possibly a better indication of probable drying rate is the

percentage of time that ambient relative humidities are below the value desirable for drying. Figure 3 shows the percent of each month, September and October, that the relative humidity is below 70 percent in each of the three states previously mentioned. This chart shows a much greater difference between the wetter area of Virginia and Georgia and the dry area of Nebraska than is indicated by the mean relative humidities. Just how this difference in time that relative humidities are below 70 percent affects grain drying has not been definitely established. However, as later discussions will indicate, it appears that for satisfactory drying with unheated air, air flow rates through shelled corn should vary in some inverse proportion to this length of time. (The relative humidity data shown in Figures 2 and 3 are indicative of the conditions which might obtain in the areas represented, but may not be true mean conditions. Weather Bureau data pertaining to relative humidity has sometimes been incomplete. The data for eastern Virginia represents only three years data, and that for Nebraska six years data taken at the experiment station supplemented by weather bureau data.)

Control of the length of drying period, when drying grain with unheated air, is obtained almost entirely by variation of the rate at which air is circulated through the grain. There are two other major factors which affect the length of drying period -- the amount of moisture to be removed from the grain and the ambient air conditions. However, these two factors are generally determined by local harvest and weather conditions. If the grain is to be dried, harvesting will likely be done at the grain moisture contents desirable for most efficient harvest. Weather variations will determine ambient air conditions, although it is possible to operate the blower intermittently to circulate air through the grain only when air conditions are favorable for drying.

The theoretical time required to dry grain from any given initial moisture content to some desired final moisture content, using unheated air, can be computed from psychrometric data and research findings when the air flow rate and ambient air conditions are known or assumed. For example, assume that shelled corn is to be dried from 20 percent moisture content to 15 percent, using unheated air, with an air flow rate of 1 cfm/bu (one cubic foot of air per minute per bushel of grain), with an average ambient air temperature of 60° F. and an average relative humidity of 70 percent. First, one bushel of corn (56 pounds at 15.5 percent moisture content) contains 11.83 pounds of water at 20 percent moisture content and 8.35 pounds of water at 15 percent, so there would be 3.48 pounds of water to remove from each bushel of corn. Second, an air flow rate of 1 cfm/bu is equivalent to 4.53 pounds of air per hour per bushel. Third, the air would enter the grain at the assumed 60° F. and 70 percent RH, if heat gain from the blower is neglected, but would leave at some decreased temperature and increased relative humidity. Nebraska experiments have shown that, when drying with unheated air forced through grain depths of about 2 feet or more, the relative humidity of the outgoing air is very approximately in equilibrium with the moisture content of the top layer of grain. Furthermore, this top layer of grain is dried very little until near the end of the drying period. Therefore, unheated air used to dry grain from 20 percent initial moisture content should leave the grain at about 92 percent RH until near the end of the drying period, and should have an average outgoing relative humidity of about 90 percent for the entire drying period. If it is assumed that the heat required to

vaporize and extract moisture from shelled corn is the same as would be required to vaporize an equal amount of water from an open pan, (an inaccurate assumption for which adjustment is made later) the heat content of the outgoing air should be very approximately the same as the heat content of the ingoing air when drying grain. From psychrometric data, it can be found that with a relative humidity of 90 percent, the outgoing air would have a temperature of approximately 56° F. if the heat content of this air were the same as for the ingoing air at 60° F. and 70 percent RH. Under these conditions, the outgoing air would contain 0.0086 pounds of vapor per pound of air as compared to 0.0077 for the ingoing air, an increase of 0.0009 pounds of vapor per pound of air circulated. Thus, an air flow rate of 4.53 lb/hr/bu (1 cfm/bu) would remove 0.0009×4.53 , or 0.004 pounds of water per bushel per hour. To remove the necessary 3.48 pounds of water per bushel would require $3.48 \div 0.004$, or 870 hours.

The drying time as computed in the preceding paragraph should be increased at least 50 percent to obtain the actual length of drying period to be expected. Experiments at Nebraska have shown that the actual drying time is about 50 percent greater than the computed time. The difference may be even greater in areas having relatively shorter periods of low relative humidity. Several factors contribute to this difference between actual and computed drying time. First, Hukill (2) has found that the heat of vaporizing and extracting moisture from the grain is substantially higher than the heat of vaporization of free water. Second, the computations are based on an average temperature and relative humidity, whereas actual ambient conditions would vary around this average with resultant variations in drying rate which would not necessarily give the same average drying rate. Third, during periods of low relative humidity grain near the air inlet would be dried below the desired final moisture content, so that more moisture would be taken out than is allowed for in the computations. During periods of high relative humidity, some moisture from the air might go back into the corn, again changing actual moisture movements from the assumed conditions.

If the computed drying period of 870 hours is increased by the recommended 50 percent, an estimated drying time of about 1300 hours, or 54 days, is found for drying shelled corn with a 1 cfm/bu air flow rate under the assumed conditions. Therefore, if it is desired to complete the drying within about 4 weeks, an air flow rate of about 2 cfm/bu would be required. To complete the drying in about 2 weeks, the air flow rate should be about 4 cfm/bu.

Recommended air flow rates for drying shelled corn are not usually computed as in the preceding paragraphs. As can be seen, these computations are quite extensive and are of such a nature that simple tables or charts cannot cover the wide range of grain moisture and ambient air conditions which may be encountered. Therefore, many states and regions have established recommendations for minimum air flow rates to be used when grain is to be dried with unheated air. These recommendations are based on experimental work or research studies which establish the requirements of a system for drying with unheated air in the area for which the recommendations are made.

A summary of several recommendations for minimum air flow rates for drying shelled corn with unheated air are shown in Table 1. It will be noted that the Georgia recommendations are higher than the recommendations in northern states, as might be expected. Also, the USDA recommendations are near an average for the several state recommendations, as is logical for a general recommendation.

Table 1.--Minimum Air Flow Rates for Drying Corn with Unheated Air.

	Georgia Recommendations		USDA Recommendations	
	Initial Grain Moisture	Minimum Air Flow Rate	Initial Grain Moisture	Minimum Air Flow Rate
	%	Cfm/bu	%	Cfm/bu
	25	6	25	5
Shelled	22	5	20	3
Corn	18	3	18	2
	15	2	16	1
Ear	25	8	30	5
Corn	18	4	25	3

Indiana -- 3 cfm/bu appears adequate for drying shelled corn from 25 percent moisture in moderate fall weather.

Nebraska -- 2 cfm/bu minimum for clean sound grain. Maximum moisture content determined by mechanical damage during harvest.

Intermittent blower operation is quite generally not recommended when grain above 15 to 17 percent moisture content is being dried. It might be expected that operating the blower only during periods of favorable ambient air conditions would reduce operating costs. However, experimental studies have indicated that the slight savings in operating cost obtained by intermittent blower operation are very often offset by the additional trouble or expense of providing for the intermittent operation. During long rainy periods, continuous blower operation will likely be uneconomical, but even during these periods the blower must be operated enough to remove accumulated spontaneous heat from the grain. When corn is high to medium in moisture content, the blower should be turned on even during rainy weather for at least 15 minutes at a time once each day in northern states and two or three times each day in southern states. If the air leaving the grain feels appreciably warmed by the grain when the blower is turned on during these cooling periods, more frequent or longer periods of blower operation should be made.

Intermittent operation of the blower may become desirable when the wettest grain in the bin has been reduced to about 15 to 17 percent moisture content. (Actually, the line of demarcation is probably at about the grain moisture content which would be in equilibrium with the average ambient relative humidity.) Further drying will be accomplished only when the relative humidity is below about 70 percent, and the grain will deteriorate very little if it is kept cool. Therefore, operation of the blower only during periods of low relative humidity may be desirable in areas where the relative humidity

is high much of the time. In Nebraska the humidity is commonly relatively low except during rainy periods, and continuous blower operation is recommended until the desired final moisture content is obtained except when rainy periods occur near the end of the drying period.

The term "blower" has been used in this discussion whenever reference to the air moving device was indicated. Actually, in unheated air drying in storage the air might be circulated through the grain either by blowing or by suction. However, blowing the air through the grain, by supplying air under pressure to the bottom of the storage, is generally preferred. Research workers generally are in agreement with the conclusions published by Hukill (3) in 1954. First, when the grain is dried by pressure ventilation, the top of the grain dries last so that the wettest grain is always readily inspected. When ventilation is by suction, the top of the grain dries first and casual inspection may lead to the conclusion that the grain is much dryer than is actually the case. Second, the resistance to air flow is greatest near the air ducts because of the high velocities in that area. In pressure ventilation, this grain dries first and shrinkage of the grain results in a net decrease in resistance to air flow. With ventilation by suction, the grain near the air ducts does not dry until near the end of the drying period and consequently a higher resistance to air flow is maintained throughout most of the drying. Third, air moving through a blower gains some heat from the energy supplied to the blower. In pressure ventilation, this heat is added to the air before it enters the grain and is therefore available for use in drying the grain. When the air is moved by suction, any heat gained from the blower is applied to the air leaving the grain and so is of no benefit so far as drying is concerned. The heat gained from a blower is a rather small quantity, but in unheated air drying even small amounts of heat may make substantial differences in rate of drying.

A blower to be used for drying grain must be selected on the basis of three considerations -- volume of air to be delivered, pressure against which this air must be delivered, and power available to operate the blower. The volume of air needed for any given drying installation is the product of the air flow rate in cfm/bu times the number of bushels to be dried at one time. Desirable air flow rates have already been discussed, and the quantity of grain to be dried is determined by the particular case being considered. Therefore, further discussion of air volumes will not be given, except to say that when all the factors listed above are considered it may be found that more than one blower and power unit will be required to meet the requirements of a given drying installation.

The pressure against which air must be delivered in a drying installation is affected by the rate of air flow used, the type of grain being dried, and the depth of grain in the drying bin. The desirable rates of air flow have already been discussed, and this paper is primarily concerned with shelled corn. Therefore, depth of grain is the principal variable yet to be discussed.

Depth of shelled corn, when drying in storage, has a direct effect on the static pressure against which the drying air must be delivered and on the power required to circulate the air. Resistance of shelled corn to air flow is shown in Table 2, based on data published by Shedd (4). In addition to the data shown in Table 2, Shedd also included in the cited publications

rather extensive statements as to the effect of different grain conditions on the resistance which shelled corn offers to air flow. Allowable grain depths as computed for several air flow rates and a maximum static pressure of 3 inches (water gage) are shown in Table 3. Computed static pressures and quantities of grain which can be dried per horsepower are shown in Table 4 for several air flow rates and grain depths.

Table 2.--Pressure Drop, Inches of Water, Per Foot Depth of Grain When Forcing Air Through Clean, Dry Shelled Corn

Air Flow Rate Cfm/sq. ft.	13.0 percent Moisture Content	12.4 percent Moisture Content
1.11	.0049	.0051
2.23	.0102	.011
4.46	.0228	.024
6.69	.0274	.040
10.03	.0648	.069
13.38	.090	.10
20.07	.170	.18
30.10	.316	.32
40.13	.502	.52

From data by Shedd (4), the 13.0% column is from table published in 1951 and the 12.4% table is from chart published in 1953.

Table 3.--Maximum Depth for Drying Corn with Unheated Air in Georgia

	Moisture Content percent	Air Flow Rate Cfm/bu	Maximum Grain Depth Feet
For Shelled Corn			
	25	6	7
	22	5	8
	18	3	9-1/2
	15	2	11
For Ear Corn			
	25 or less	8-4	20

The effects of variations in grain depth and air flow rates on static pressures, power requirements, and operating costs can be summarized by the following statements. These statements were based originally on research findings at Nebraska, but are in general agreement with other research results. First, assuming a constant air flow rate, in cfm/bu, is to be circulated through different depths of grain, then: The static pressure against which the air must be delivered varies approximately as the square of the grain depth; The power required to circulate the air varies approximately as the square of the grain depth, when power is expressed as KW or HP per bushel being dried, or as the cube of the grain depth, when power is expressed as KW or HP per square

foot of bin floor area; Power costs for circulating the air, expressed in cents per bushel of grain dried, vary approximately as the square of the grain depth for similar grain moisture and ambient air conditions. Second, assuming a constant grain depth is to be supplied with different rates of air flow, in cfm/bu, then: Static pressures increase at only a slightly greater rate than in direct proportion to the air flow rate; Power required to circulate the air will increase about as the square of the air flow rate, with power expressed either as KW or HP per bushel or as KW or HP per square foot of bin floor area; Operating costs, expressed in cents per bushel, will increase in slightly greater than direct proportion to the air flow rate, for similar grain moisture and ambient air conditions.

The optimum depth for drying shelled corn with unheated air would probably be about 6 feet, when the relationships of the preceding paragraph are considered. This would give a reasonable balance between the cost per bushel for purchasing and operating the drying equipment and the cost per bushel for the storage, if new storages were being built. However, in most cases the drying will be done in existing structures, and greater grain depths may be desirable. Nebraska has generally recommended a maximum grain depth of 8 feet for any grain to be dried from 20 percent or higher moisture content. USDA recommendations for maximum grain depths are shown in Table 5. In general, if grain depths exceed these recommendations, either the air flow rate must be so high that drying costs become somewhat prohibitive or the grain in the top part of the storage will not be dried fast enough to prevent deterioration during drying.

Table 4.--Effect of Various Air Flow Rates and Grain Depths on Static Pressure and Drying Capacity per Horsepower

Air Flow Rates Cfm/bu	Grain Depth Ft.	Static Pressure In. Water Gage	Max. Quantity per Fan HP Bu.
6	3	0.60	885
	5	1.50	360
	7	3.20	170
5	4	0.70	860
	6	1.60	380
	8	3.40	190
3	6	0.90	1120
	8	1.50	670
	10	2.65	400
2	6	0.60	2500
	8	0.90	1670
	12	2.20	680
1	8	0.50	6000
	12	1.00	3000
	16	1.60	1880

Static pressure includes 0.25 in. for duct friction loss
Air flow assumed--3000 cfm per HP at 1-inch st. pressure

Table 5.--USDA Recommendations for Drying Shelled Corn with Unheated Air

Initial Grain Moisture	Recommended Minimum Air-Flow	Practical Grain Depth	Static Pressure
%	Cfm/bu	Feet	In. Water Gage
25	5	4	0.7
		6	1.6
20	3	6	0.9
		8	1.5
18	2	6	0.6
		8	0.9
		12	2.2
16	1	8	0.5
		12	1.0
		16	1.6

Static pressure includes 0.25 in. for duct friction loss.

The size of a drying system for unheated air drying in storage will often be limited by the power available to circulate the air. This is particularly true when electrical power is to be used in rural areas. Rural power districts usually limit the size of motor which can be connected to a single phase power supply, with 5 or 7-1/2 horsepower about the maximum allowable in most areas. The experience in Nebraska has been that although farmers may install drying systems to be operated by internal-combustion engines, almost invariably they will switch to electrical power within two to three years if the electrical power is available. Therefore, permissible electric motor sizes will generally limit the size of a drying system. Data in Table 4 indicates the quantity of grain which can be dried per horsepower for several flow rates and grain depths.

The time required to dry grain with unheated air depends upon several factors, the most important of which are initial and final grain moisture contents, ambient weather conditions, rate of air flow, and method of blower operation.

The length of drying period will increase in some direct relationship to the amount of moisture to be removed from the grain, and so in some direct relationship to the difference between the initial and final moisture content of the grain, if the other factors remain constant. However, there is no definite proportion to this relationship, since grain with a high moisture content dries somewhat faster than grain lower in moisture content. Also, under some ambient conditions moisture can be removed from high moisture grain with air which would not dry low moisture grain at all.

Ambient weather conditions quite naturally affect the length of drying period when drying grain with unheated air, since the ambient temperature and relative humidity determine the amount of moisture the drying air can remove from the grain. It is difficult to establish any definite relationship between drying rate and ambient temperature, since temperature changes are often accompanied by simultaneous changes in relative humidity. However, for seasonal differences in temperature when relative humidity differences are less than proportionate to temperature differences, a drop of 10° to 15° F. in temperature will usually at least double the drying time. If relative humidity differences were proportionate to the temperature differences, changes in ambient temperature would have a much greater effect on the length of drying period.

The length of drying period will vary in some direct relationship to the ambient relative humidity. For a constant temperature, this relationship should be such that the length of drying period varies in inverse proportion to the "spread" between the ambient relative humidity and the relative humidity at which the air would be in equilibrium with the grain. However, when drying with unheated air the relative humidity of the drying air cannot be controlled, except by operating the blower intermittently only during the periods of low relative humidity. Such intermittent blower operation will reduce the actual operating time, but generally increases the overall length of drying period. When the grain has a higher moisture content than would be in equilibrium with the average ambient relative humidity drying will be faster with continuous than with intermittent blower operation. For dryer grain, intermittent blower operation will give at least as fast, and often faster, drying. The indicated break between continuous and intermittent operation will usually come at grain moisture contents in the range of 15 to 17 percent.

The length of drying period will ordinarily vary in almost perfect inverse proportion to the air flow rate, in cfm/bu. The air leaving grain will be very nearly in equilibrium with the moisture content of the grain regardless of air flow rate for all air flow rates generally used in unheated air drying in storage. Therefore, the air is just as effective at high flow rates as at low rates and moisture removal should be in direct proportion to the quantity of air moved.

The cost of drying grain in storage with unheated air is hard to establish. Actual operating costs, or cost of power to operate the blower, usually range from 1 to 4 cents per bushel. However, other costs must be considered. Since the grain is dried in storage there will usually be no extra handling costs assignable to the drying, except that storages may be less efficiently used because of grain depth limitation. There will be the fixed costs of providing the blower and power unit and adapting the storage bin for drying. The initial cost for blower, power unit, and storage adaptation will be anywhere from a minimum of about 20 cents up to a maximum of possibly 50 cents per bushel of drying capacity. The part of this fixed cost which can be charged to each bushel of grain dried will depend on the efficiency with which the equipment and drying system is used. If minimum air flow rates are used to minimize operating costs it will likely be possible to dry only one "batch" of grain each harvest season. If the drying equipment cannot be otherwise used than for this one batch of grain each year, fixed costs may be 10 percent or more of the initial cost. If relatively high air flow rates are used in

drying grain, possibly more than one batch of grain can be dried each season, or possibly the equipment will be freed for other use which will reduce the fixed costs chargeable to grain drying. In such cases, fixed costs might be less than 5 percent of the initial cost. Therefore, it appears that the overall cost for drying grain with unheated air would likely be not much above 6 cents per bushel, and might be as low as 2 or 3 cents per bushel.

Distributing the drying air through the grain is the one important phase of drying which has not yet been discussed. Since the subject of this discussion is drying in storage, only those air distribution systems used in storage bins will be discussed. Such systems can be divided into two general classes -- those providing for parallel air flow, and those providing for non-parallel air flow.

Air distribution systems for parallel air flow have some form of false floor supported above the regular floor of the storage bin. The false floor may be hardware cloth supported on a lattice-like sub-floor, or may be a perforated metal floor. The perforated metal floor will cost more than hardware cloth, but usually requires less support so that the total cost may be no greater for the installed floor. (See illustrations, USDA Leaflet No. 332, "Drying Shelled Corn and Small Grain with Unheated Air.") Area of air openings through the false floor should total at least 7 percent of the total bin floor area. The principal advantage of the false floor type of air distribution system is that uniform air distribution, and therefore uniform drying, will be obtained even where very shallow grain depths are being dried. There are two definite disadvantages of this type of system. First, the installation cost will usually be appreciably higher than for the non-parallel flow duct type of system. Second, some grain and chaff tends to sift through the floor, so that the false floor must usually be removed if the storage bin is to be cleaned thoroughly.

Several different types of ducts have been used in non-parallel flow air distribution systems. This type of system usually has a plenum, or supply duct, with several lateral ducts to distribute the air over the bin floor. The system may be built of wood, or may use commercially produced ducts of sheet metal. Ducts built of wood often require the least cash outlay, since the operator can use his own labor for construction. The lateral ducts are simply inverted troughs supported above the regular bin floor, so that air can flow out through the ducts then under the lower edges into the grain. Nebraska recommendations for the design of a lateral duct system have been for 1 square foot of opening for each 1000 cfm of air to be handled, both in the main duct and in the laterals. Systems designed by others on the basis of 1 square foot of opening for up to 2000 cfm of air have apparently given satisfactory results. Nebraska recommendations as to the distance the ducts should be raised above the floor has been that the total area of cracks between ducts and floor should be at least 12 percent of the floor area. Recommendations by others have been that this crack area should be as much as 25 percent of the floor area.

The principal advantages of the lateral duct type system are that it usually is relatively low in first cost, as compared to the perforated floors, and that the ducts can be simply laid in place and so are easily removed for thorough cleaning of the bin. The main disadvantage is that drying air is not uniformly distributed through the bottom of the bin and grain will not be dried uniformly when shallow depths of grain are to be dried.

Uniformity of drying can usually be obtained with lateral duct type systems only when the grain depth is at least as great as the spacing between ducts, according to tests at Nebraska. Nebraska has recommended a duct spacing of two feet. Other recommendations have been for spacings as high as 6 feet. Apparently, any spacing up to 6 feet will give satisfactory drying if the grain depth is properly correlated with duct spacing. It is doubtful that lateral duct spacings greater than 6 feet should be used.

There have been several variations in duct type air distribution systems tried for drying grain in storage. In general, it appears that the further these systems diverge from the basic ideas of a parallel flow system, the greater will be the problem of obtaining satisfactory drying in all drying situations.

In closing, it should be made clear that all the preceding discussion is based on the assumption that reasonably sound and clean grain is to be dried. The specified limitations on operation and design of a drying system will necessarily be considerably narrowed if unclean or unsound grain is to be handled. Furthermore, with reasonably clean and sound grain, care should be taken in placing the grain on the drying system so that no significant accumulation of chaff or cracked grain occurs in any part of the bin.

BIBLIOGRAPHY

1. Foster, George H., Minimum Air Flow Requirements for Drying Grain With Unheated Air. *Agricultural Engineering*, Vol. 34, No. 10, pages 681-4, October 1953.
2. Hukill, William V., Basic Principles in Drying Corn and Grain Sorghum. *Agricultural Engineering*, Vol. 28, No. 8, pages 335-40, August, 1947.
3. Hukill, William V., Grain Drying with Unheated Air. *Agricultural Engineering*, Vol. 35, No. 6, pages 393-405, June, 1954.
4. Shedd, C. K., Some New Data on Resistance of Grains to Air Flow. *Agricultural Engineering*, Vol. 32, No. 9, pages 493-520, September, 1951.
Resistance of Grains and Seeds to Air Flow. *Agricultural Engineering*, Vol. 34, No. 9, pages 616-19, September, 1953.

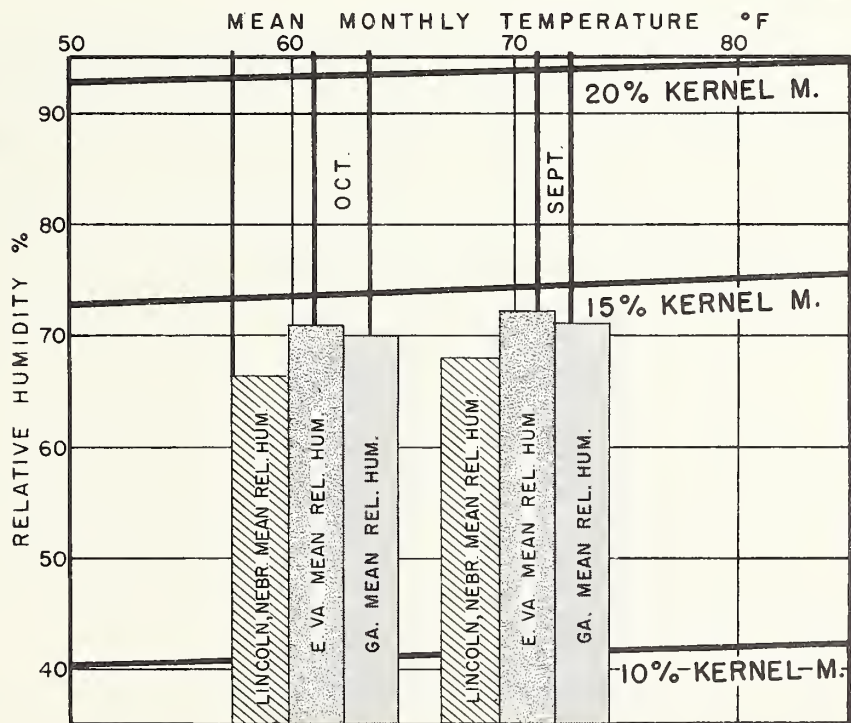
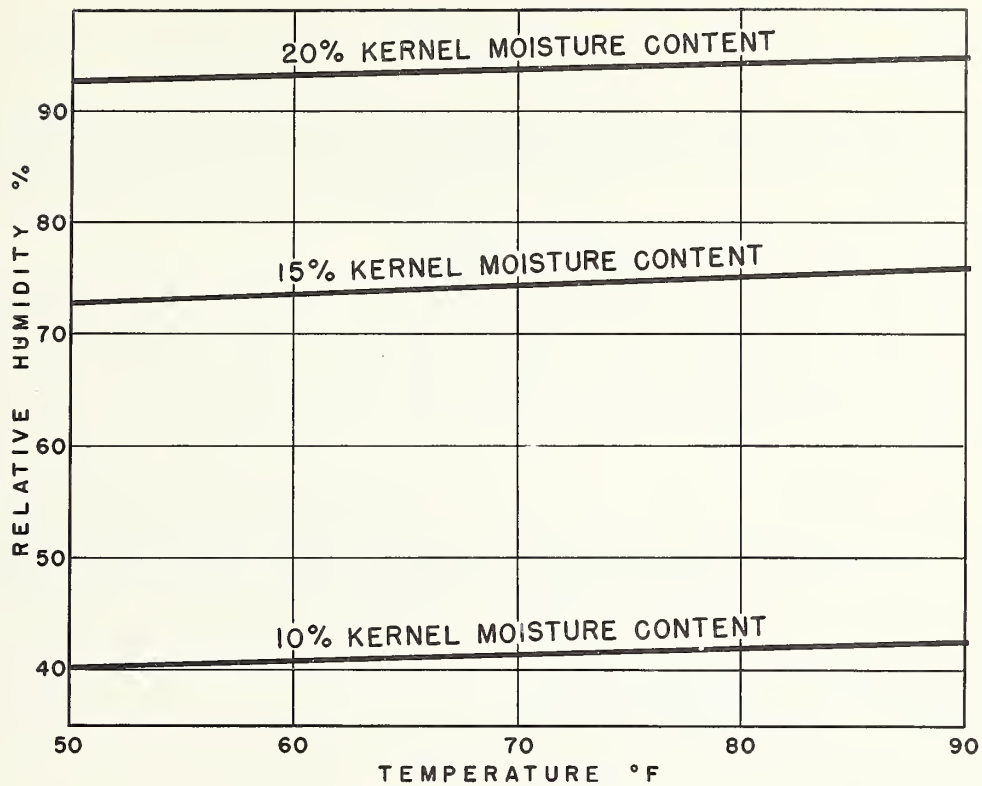


Figure 1.--(Top) Equilibrium moisture content of shelled corn in relation to air temperature and relative humidity.

Figure 2.--(Bottom) Mean monthly temperature and relative humidity in September and October at 3 locations, superimposed on the equilibrium chart of Figure 1.

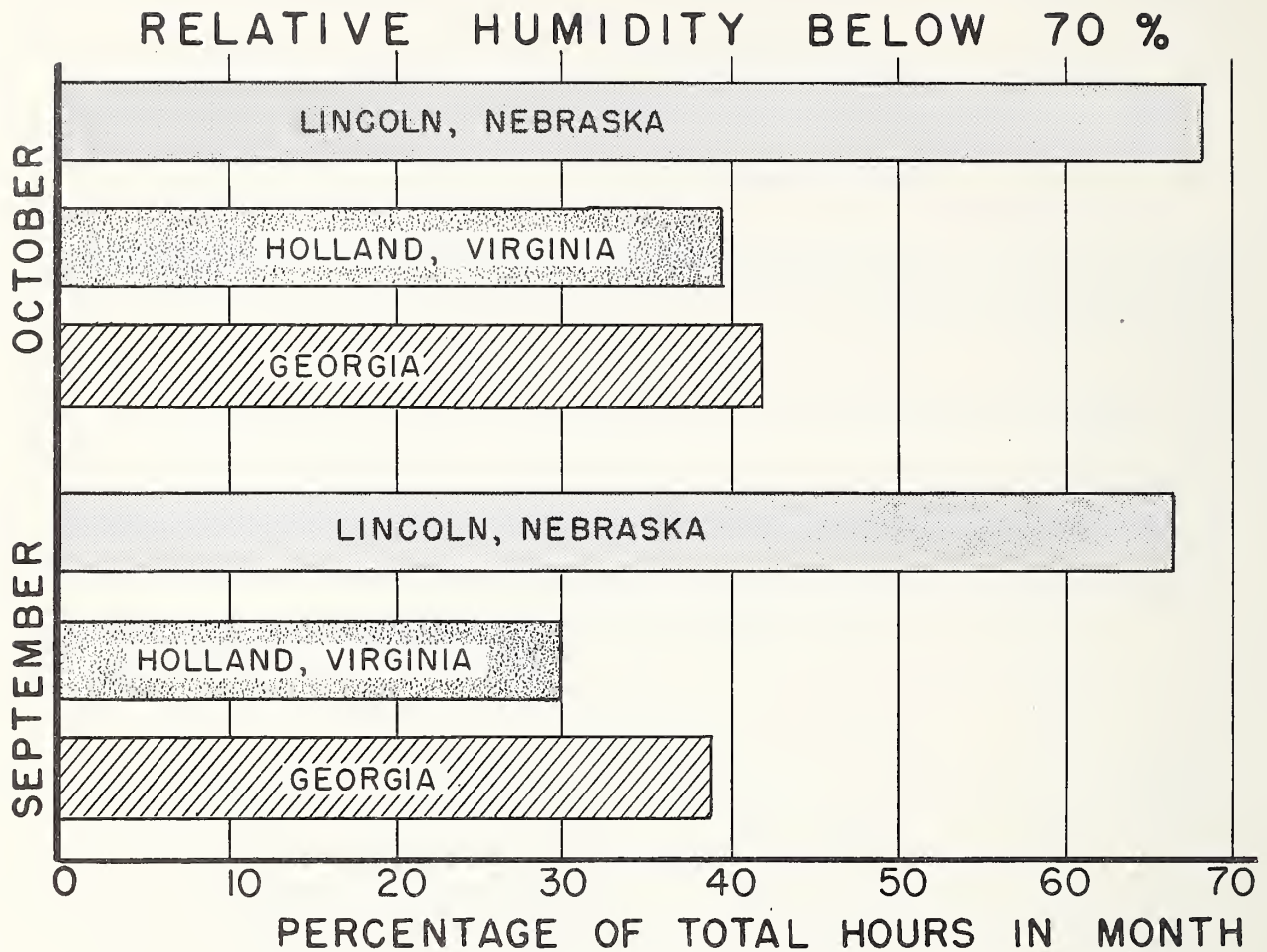


Figure 3.--Percent of time that relative humidity at 3 locations is below 70 percent during September and October.

SUPPLEMENTAL HEAT FOR DRYING-IN-STORAGE

by

H. J. Barre
Consulting Agricultural Engineer
Mansfield, Ohio

Supplemental heat is necessary to reduce the drying time during periods of cool and humid weather during September and October when corn is harvested. It is also necessary to reduce its moisture content to a safe level for subsequent storage. Supplemental heat should be distinguished from artificial heat in drying grain. The air is heated only a few degrees, a maximum of about 20 degrees. There are periods, especially during the daytime, when supplemental heat is not necessary for satisfactory drying.

In an analysis of "drying-in-storage" with or without supplemental heat, the relationships of several factors must be taken into consideration. These include (a) air flow, (b) psychrometric conditions of the air, (c) moisture content of the corn, and (d) maximum permissible time to dry. Some important relationships of these factors will be discussed briefly, followed by a statement of requirements for air flow and heating capacity for supplemental heat in relation to wide fluctuations in temperature and humidity of the unheated air.

Maximum Permissible Drying Time

An important consideration in drying all kinds of crops, including hay, is the maximum time permissible to complete drying. The longer the drying time the more economical it is. Both equipment and operating costs are less. The maximum permissible time varies widely with the psychrometric conditions of the drying air and with the moisture content of the grain up to 25 percent. The most important single factor which determines the available time to dry is the wet bulb temperature because it is the temperature to which the undried grain is subjected before it is completely dried. The temperature of the grain determines the rate at which it deteriorates. In the case of mold development it determines the rate at which the various fungi grow.

Figure 1 presents some limited data on shelled corn by Semeniuk (4). Data for hay by Terry (5) are also shown. The data for hay indicate that mold development takes place until a temperature of 80 to 100 degrees is reached. At higher temperatures the development of molds is inhibited. Data above 100° F. were not determined for shelled corn but it is probable that fungus growth at the higher temperatures would likewise be inhibited. However, other forms of deterioration such as fat acidity may become increasingly greater.

Small-scale experiments by Foster (2) during the Fall of 1952 in Central Indiana indicate that a continuous air flow rate of 3 to 4 cfm per bushel can be used for drying shelled corn without appreciable deterioration. Assuming an air flow of 3-1/2 cfm per bushel the maximum permissible time to dry is about 30 days with a mean wet bulb temperature of about 42 degrees.

Teter (6) of the U. S. Department of Agriculture at the Tidewater Experiment Station at Holland, Virginia, suggests an air flow of 16 cfm per bushel for drying shelled corn with a moisture content of 25 percent. At a wet bulb temperature of 68° F. and wet bulb depression of 5.5° F*, the time available for drying is about 4-1/2 days, which is not much greater than that for hay.

Although the data for shelled corn are very meager, it is apparent that there is a pronounced relationship of the maximum available time to dry to the wet bulb temperature to which the undried corn is subjected. The much higher values of the data by Semeniuk are largely due to a lower humidity than 100 percent and the low initial moisture content of the corn of 13 percent.

Relation of Drying Time to Dew Point and Wet Bulb Depression

According to the analysis of drying grain by Hukill (3), the wet bulb depression represents the maximum amount of sensible heat in the drying air available for removing moisture from grain. But the amount of moisture removed for a given wet bulb depression and air flow is less at higher dew points and dry bulb temperatures due to an increase in equilibrium moisture content at a higher dew point.** Therefore, either the dew point or the dry bulb temperature must be taken into consideration in addition to the wet bulb depression to determine the time to dry to a given moisture content. It is more appropriate to use the dew point because it remains constant when sensible heat is added to the drying air.

Any combination of these two factors, the wet bulb depression and the dew point, determine not only the drying time and the equilibrium moisture content, but also the wet bulb temperature of the drying air (also that of the undried grain). Figure 2, which has been prepared from standard psychrometric data, shows the relationships of the latter to these two factors.

Figure 3 shows the relationship of time to dry shelled corn with an initial moisture content of 25 percent and at an air flow of 5 cfm per bushel to these two factors. The equilibrium moisture content to which the shelled corn will dry is also determined by these two factors since a combination of dew point and wet bulb depression determines the relative humidity of the drying air.

Dew Point and Wet Bulb Temperature Data for September and October

In determining the requirements for supplemental heat for drying-in-storage it is essential to know the relationship of weather to the two important factors just discussed; namely, the wet bulb depression and the dew point. With appropriate psychrometric data published monthly by the Weather Bureau (7), one can easily determine the magnitudes of the wet bulb depression and the dew point for any period. The extremes in variation from the mean values

* Based on weather data for September 1954 and 1955 for Norfolk, Virginia.

** Stated in another way, the time required to dry to a given moisture decreases as the dew point of the drying air increases. This is due to the higher wet bulb depression necessary to obtain the same relative humidity of the drying air or the same equilibrium moisture content of the grain.

for each of these can also be determined. The accompanying table shows the monthly mean temperature data for three widely separated locations. Data for Lake Charles, Louisiana, and Sacramento, California, are included primarily for purposes of comparison. The data presented are reasonably self-explanatory. In addition to the monthly means, the Standard Deviations are also given.

A few comments are worthy of note. September 1951 for Des Moines represents poor drying conditions; 1953 represents the other extreme, good drying conditions. (The values for these two extremes are indicated on the graphs in Figures 2 and 3.) The mean wet bulbs are nearly the same for each of the two years, being a little over 55 for 1951 and a little less than 55 for 1953. In Figure 3 the mean dew point of 52 degrees and the mean wet bulb depression of 4.9 represent a relatively poor drying condition. At a rate of 5 cfm per bushel, 16 days would be required to dry the grain to a moisture content of a little more than 15 percent. The relatively good drying conditions with a mean dew point of 46 degrees and a mean wet bulb depression of 11 degrees permit the shelled corn to be dried to a moisture content of a little more than 11 percent in about 9 days. Any other data can similarly be evaluated with the aid of these two charts for days to dry, the moisture content to which it will dry, and the temperature of the undried grain.

With appropriate statistical analyses, it is possible to determine also the probability of extremes in variations from these means for periods of any duration. For example, one should be able to determine the frequency with which a given dew point in combination with a given wet bulb depression will occur over a period of any number of days. This then would serve as a basis for evaluating the requirements for supplemental heat for probable extremes for which any given installation should be designed. This is similar to the design of dams which are usually constructed to take care of floods once in 25, 50 or 100 years.

Requirements for Supplemental Heat

With the information in Figure 3 it is possible to determine the maximum temperature rise and the total heat necessary to dry a given quantity of grain to a selected moisture content. To illustrate more clearly, reference is made to Figure 4 which gives the dew point, the wet bulb depression and the difference between the dry bulb and the dew point for the month of September, 1951 at Des Moines, Iowa. The data for each 6-hourly period throughout the entire month as well as the mean values for each of the items are given. The fluctuations of the dew points and wet bulb depressions are rather typical. The former fluctuates from less than 30 to more than 70 degrees. The mean wet bulb depression is 4.9 degrees with a standard deviation of 3.7 degrees.

In order to dry the shelled corn to a moisture content of 12 percent it will be necessary to maintain a wet bulb depression of about 10 degrees. For a dew point of 60 degrees the wet bulb depression should be from 10 to 11 degrees. Toward the latter part of the month as the dew point drops below 40 degrees, the wet bulb depression should only be about 8 degrees.

In the upper part of the chart in Figure 4 the differences in the dry bulb temperature and the dew points are given. This is presented to show the temperature differential between the dry bulb and the dew point which needs

to be maintained to dry shelled corn to a moisture content of 12 percent. This differential is fairly constant throughout the entire month, varying even less than the wet bulb depression. A difference of 16 to 17 degrees needs to be maintained. By comparing this with the differences of the dry bulb temperatures and the dew points of the unheated air at each six-hour interval it is apparent that supplemental heat during this particular month needs to be supplied almost constantly. The difference varies from 0 to a maximum of 16 to 17 degrees, the mean difference for the entire month being about 8 to 9 degrees.

From this information it is fairly simple to arrive at the maximum heating capacity and the total heat required for any drying period. Let us take for example, the drying of 1000 bushels of shelled corn with a moisture content of 25 percent at an air flow of 5 cfm per bushel, under weather conditions represented by September, 1951 at Des Moines, Iowa. The time required to dry to a moisture content of 12 percent is about 9-1/2 days (Figure 3), at the mean dew point of 52° F. A temperature differential of about 16-1/2° F. between the dry bulb and dew point is required to maintain the wet bulb depression of 10° F. With a mean temperature differential of 8-1/2° F. of the unheated air, a mean temperature rise of 8° F. is required. The total heat required is about 9.1 million Btu's. The maximum heating capacity for a maximum temperature rise of 16-1/2° F. is 82,500 Btu's per hour regardless of whether the heater is of a modulating or intermittent type.

Automatic controls to maintain a selected humidity of the drying air are very essential for satisfactory performance. Manual control, in addition to the frequent attention required, leaves too much to chance, with the result that excessive overdrying may occur or the required supplemental heat is not provided at all times.

Over-Drying and the Possibility of Re-Wetting

It is readily apparent from Figure 3 that to dry grain more rapidly or to increase the drying capacity one could increase the wet bulb depression by heating the air still more or by increasing the air flow per bushel. Considerable reduction in drying time would be effected. However, an increase in air flow is somewhat impractical because of the larger power requirements. Hence, the higher temperature is the only alternative. This may be done but at the expense of over-drying, especially at the point of the incoming air. In some field experiences the grain has purposely been overdried and moisture added by blowing unheated air through the dried grain during periods of more humid weather. This was reasonably satisfactory but more research and experience is required to make specific recommendations.

Summary

Supplemental heat for drying-in-storage offers some real possibilities in conditioning high-moisture shelled corn on the farm. It eliminates the uncertainty of unfavorable weather which occurs too frequently and which does not permit complete and rapid enough drying. The added operating cost for fuel is offset by the lower power cost of the fan. With bins equipped with perforated floors and with adequate fan capacity and heater with proper controls,

it requires very little attention on the part of the farmer. If the grain is to be stored after it is dried, the equipment including the bins, fan, and heater, can be selected to meet the requirements to handle almost any desired quantity of shelled corn including a drying capacity consistent with the rate of harvest. The investment costs are usually less, especially if some or all of the present storage can be adapted for drying.

REFERENCES

1. Coleman, D. A. and Fellows, H. C. Hygroscopic Moisture in Cereal Grains. Cereal Chem. 2:275-287. 1925.
2. Foster, G. H. Minimum Air Flow Requirements for Drying Grain. Agr. Engr. Jour. 34:681-84. 1953.
3. Hukill, W. V. Drying of Grain. Storage of Cereal Grains and Their Products. Chapter IX. 402-435. Monograph Series Vol. II. American Association of Cereal Chemists. 1954.
4. Semeniuk, G., Nagel, C. M., and Gilman, J. C. Observations on Mold Development and on Deterioration in Stored Yellow Corn. Iowa Agr. Expt. Sta. Res. Bull. 349. 1947.
5. Terry, C. W. Relation of Time and Operating Schedule to Hay Quality, Mold Development, and Economy of Operation. Agr. Engr. Jour. 28:141-144. April 1947.
6. Teter, N. C. Tidewater Research Station, Holland, Va. Private Correspondence. Dec. 21, 1954.
7. Weather Bureau. U. S. Dept. of Commerce. Local Climatological Data Supplement. Published monthly. Supt. of Documents, Govt. Printing Office, Washington, D. C.

MEAN MONTHLY TEMPERATURE DATA FOR SEPTEMBER AND OCTOBER IN THREE WIDELY SEPARATED LOCATIONS
 (From Weather Bureau Supplements with readings every six hours.)

Place	Year	SEPTEMBER						OCTOBER					
		Dew Point.			Wet Bulb			Dew Point.			Wet Bulb		
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Des Moines, Iowa	1951	52	9.4	56	8.7	4.9	3.7	44	10.7	48	10.6	4.5	3.7
	1953	46	7.8	55	7.3	11.0	6.8	41	8.6	50	11.1	9.2	5.5
	1954	54	8.9	59	9.8	7.8	5.8	43	13.2	48	11.0	4.4	3.7
Lake Charles, Louisiana	1955	72	5.2	74	2.5	5.3	4.6	56	12.3	61	3.0	7.4	5.4
Sacramento, California	1951	53	6.8	60	5.4	10.3	6.4	46	3.6	54	5.2	8.5	7.8

S.D. - Standard Deviation.

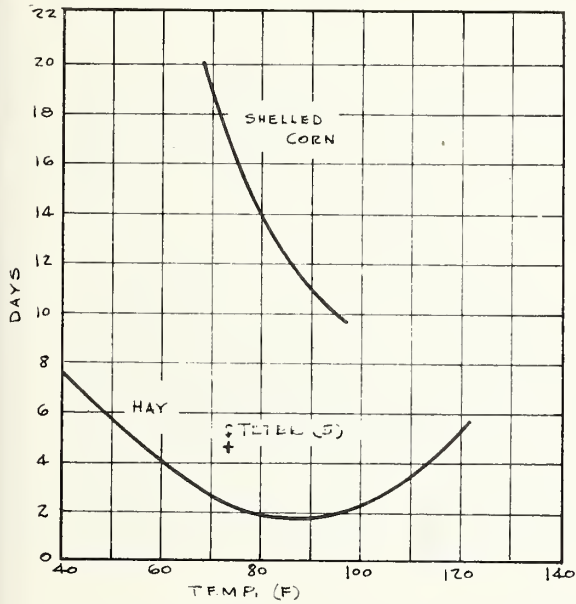


Figure 1.--Days to Appearance of Mold in Hay and Shelled Corn in Relation to Temperature and Relative Humidity. Shelled corn is for an initial moisture content of 13 percent and a relative humidity of 97-1/2 percent. Data for hay is by Terry (4). That for shelled corn by Semeniuk (3).

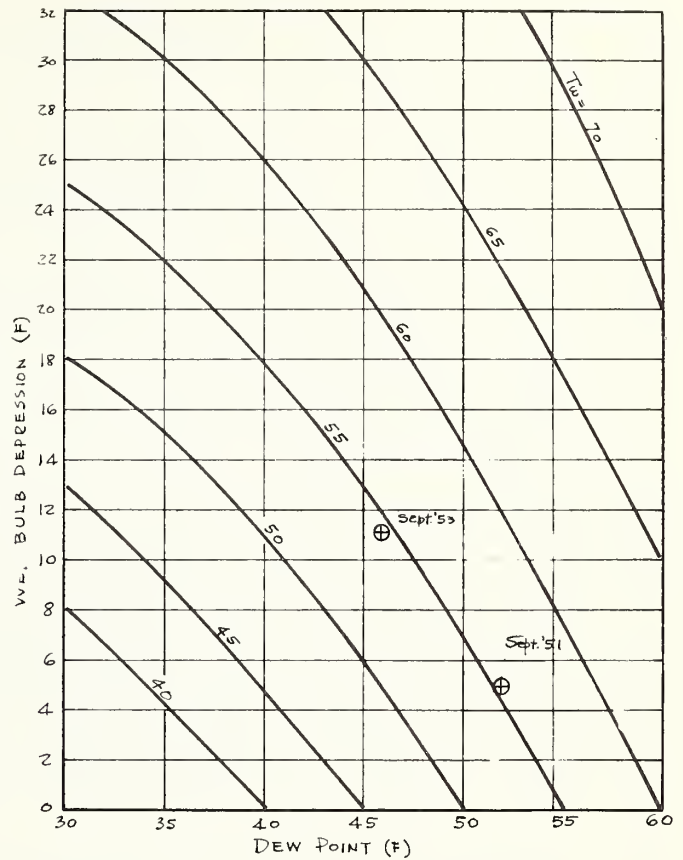


Figure 2.--Wet Bulb Temperature in Relation to Dew Point and Wet Bulb Depression.

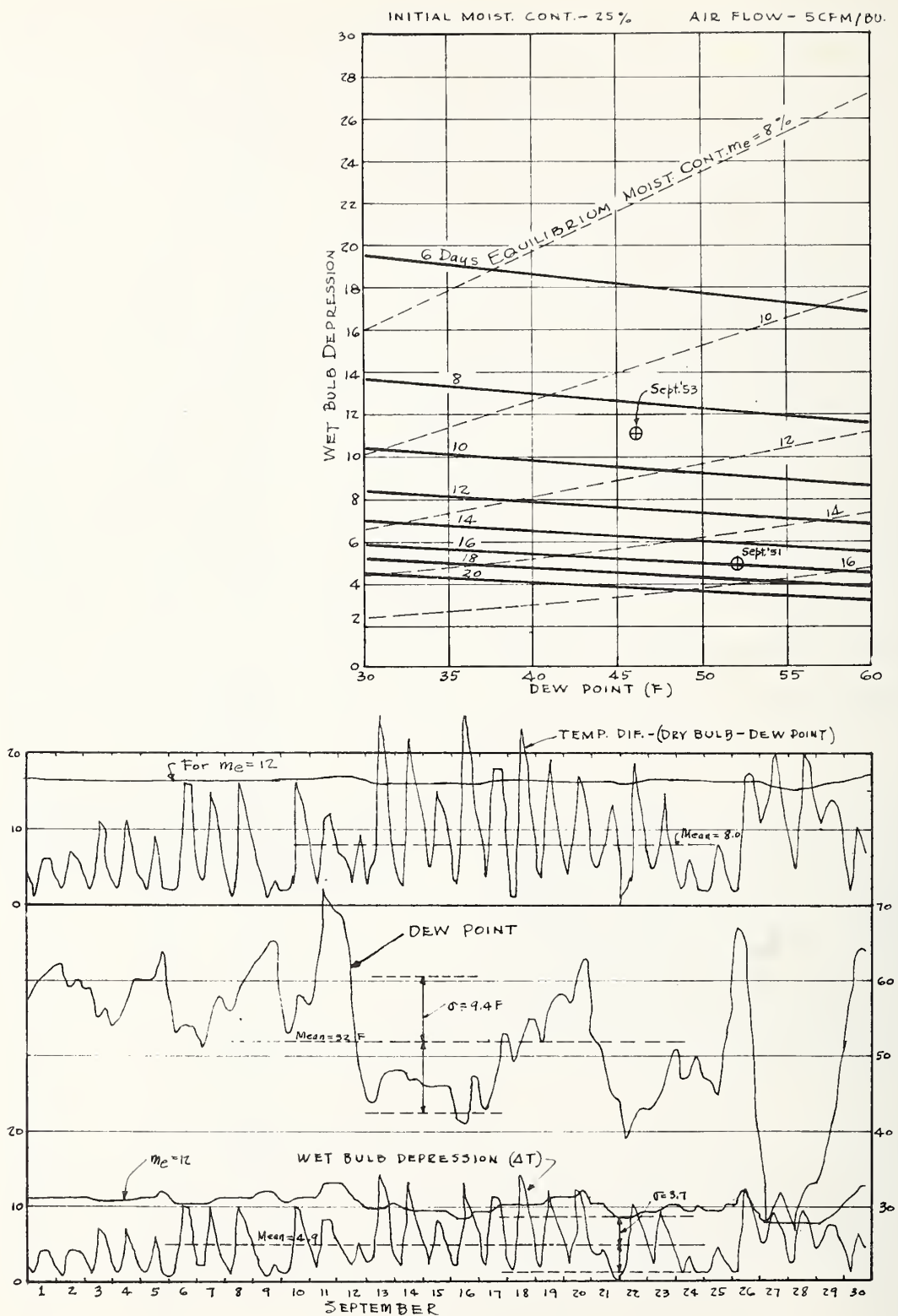


Figure 3.--(Top) Days to Dry and Equilibrium Moisture Content in Relation to Dew Point and Wet Bulb Depression of the Drying Air. Equilibrium moisture content data from Coleman and Fellows (1). Times to dry based on final moisture content of 18% in last layer to dry.

Figure 4.--(Bottom) Temperature Data for September 1951 at Des Moines, Iowa.

HEATED AIR DRYING OF SHELLED CORN - BATCH AND CONTINUOUS DRIERS

by

Nolan Mitchell, Sales Manager
Aerovent Fan and Equipment, Inc.
Lansing, Michigan

Farm size grain driers are no longer a novelty. Grain drying, until recently an emergency measure in wet seasons, is rapidly becoming standard practice among the more efficient grain producers and is giving them a much better control on both harvesting and marketing. The introduction of the picker sheller or the corn combine has made drying grain on the farm a must.

Like the chicken and the egg, it is hard to determine which should come first -- field shelling or corn drying. It is a definite fact that when the field shelling method of corn moves in, the drying just has to follow. It is very seldom that corn gets dry enough in the field to shell and store as shelled corn. This is one fact that is rather difficult for a lot of farmers to realize. For years they have been accustomed to picking ear corn at moisture contents above 20%, storing it in slatted cribs and getting by in fine shape. Even harvesting corn by this method, quite frequently, farmers have found that in order to get the corn dry enough to store even in the ear it was necessary to use drying equipment.

To sell shelled corn without dockage it is necessary to have it down to 15½% moisture content. If a farmer is planning to store shelled corn for any length of time, or seal it under the price support program, it has to be down to at least 13% moisture. Most people, who are at all familiar with the production of corn in this country, know that very seldom does the corn get down to 13% in the field.

I am quite sure that today many farmers who are purchasing corn combines or picker shellers, or who plan to do so, are doing it with the idea in mind that the local elevator will dry the corn for them. Farmers who are thinking in this direction may be in for quite a surprise. It probably has not occurred to them that four to six corn combines in a community can overload most any of the elevator driers that are in operation today. Even where the local elevator drier has sufficient capacity to handle the corn from the picker shellers in its service area, the farmers carrying corn to be dried may be sadly disappointed in the amount of time spent in waiting for the elevator to dry corn already on hand and be able to take the load which they have waiting. Most of the farmers who are using corn combines and picker shellers are starting to harvest corn at moisture contents anywhere from 25 to 30%. This harvesting equipment at the present time apparently will handle the crop very nicely in this range of moisture content. This also enables the farmers to get their crops out of the field earlier while the weather is good, and the ground is in good condition for operating machinery. In fact this is one of the big assets of having crop drying equipment available.

Not many people fully understand the amount of moisture that must be evaporated to dry corn of these moisture contents down to marketable moisture or moisture content safe for storage, without danger of damage. Table No. 1 shows the pounds of water that must be evaporated to obtain one bushel, or 56 pounds of moisture contents of $15\frac{1}{2}\%$ and 13% . By observing this data, it is readily seen that when drying corn from a moisture content of 26% to a safe moisture content of 13% it is necessary to evaporate approximately 9.8 pounds of water for each dry bushel obtained. By using a little arithmetic, it is readily seen that in order to obtain 1000 bushels of 13% corn, when starting with an initial moisture content of 26% , it is necessary to evaporate 1000×9.8 or 9,800 pounds of water.

Assuming that one corn combine can harvest 1000 bushels of shelled corn per day, six can harvest 6000 bushels. To dry 6000 bushels of shelled corn will require the evaporation of $6 \times 9,800 = 58,800$ pounds of water. If the elevator drier operates on a schedule of 24 hours per day, to dry the corn from six combines, the drier will have to have a capacity to evaporate $\frac{58,800}{24} = 2450$ pounds of water per hour. Experience indicates that it requires 2000 BTU's output of a drier to evaporate one (1) pound of water. The total heat output required is $2450 \times 2000 = 4,900,000$ BTU's per hour. This heat output will require approximately 40 to 45 gallons of fuel oil or 55 gallons of LP gas per hour. Very few elevator driers have this much capacity. These are the facts that make it impracticable for one elevator drier to attempt to handle the corn from very many corn combines in their service area.

Grain drier design is keeping pace with improvements in other speeded up phases of mechanized agriculture. Today there is available some type of drying equipment to fit practically every farm situation that exists or may develop. Drying systems are usually classified according to whether the air used as a drying medium is heated or not. There are three major classifications:

1. Natural air drying
2. Natural air drying with supplemental heat
3. Heated air drying

When using natural air as a drying medium, as a usual thing the grain is dried in deep bins, or in bulk. The quantity to be dried may vary anywhere from a few hundred bushels to several thousand bushels. The depth of the grain to be dried may vary anywhere from two feet to eight or ten feet. A natural air drying system uses the drying capacity of the atmosphere to dry the material. Large quantities of air are blown through the product by means of a fan. When the weather is warm and dry the rate of drying is fast; when the weather is wet and cold, of course, the rate of drying is quite slow. Since heating the air increases the rate of drying, many natural air drying systems now are employing some supplemental heat during periods of adverse weather conditions or in areas where the relative humidity is quite high. As a usual thing the same type of container is used to hold the grain being dried when supplemental heat is applied to natural air. Usually the term 'supplemental heat' indicates only a few degrees of

TABLE NO. I

WATER TO BE EVAPORATED WHEN DRYING SHELLLED CORN

DRIED & SOLD IMMEDIATELY

<u>Initial Moisture Content (Wet Basis)</u>	<u>Final Moisture Content (Wet Basis)</u>	<u>Pounds Water to be removed per Dry Bu. 56 lbs.</u>
35%	15.5%	16.8 lbs.
30%	15.5%	11.6
28%	15.5%	9.7
26%	15.5%	7.9
24%	15.5%	6.3
22%	15.5%	4.7
20%	15.5%	3.2
18%	15.5%	1.7
16%	15.5%	0.3

DRIED & STORED

35%	13%	19.0 lbs.
30%	13%	13.6
28%	13%	11.7
26%	13%	9.8
24%	13%	8.1
22%	13%	6.5
20%	13%	4.9
18%	13%	3.4
16%	13%	2.0

temperature rise, or just enough heat added to the natural air to create good dry summer time air conditions.

When heated air drying is employed, management practices must be considerably different from those used with natural air or supplemental heated air drying. Most experience has indicated that when using heated air it is not satisfactory to attempt to dry shelled corn or grain in deep layers. The corn at the bottom of the bin, where the hot air first enters, will always be considerably over-dried before the grain near the surface is dry. The surface corn may remain quite wet during the drying process. If the batch is so large that more time than 24 hours is required mold may develop in the top corn.

In heated air drying enough heat is added to the air so that practically all of the drying obtained results from the heat added and only a small percentage of the drying is accomplished by the atmospheric heat contained in the drying air. For satisfactory results shelled corn or grain must be dried in thin layers when heated air is used. Any heated air drying system consists of some type of heater, a fan for forcing air through the product and a container to hold the grain, with some type of air distribution system for distributing the air as evenly as possible through the product, so uniform drying will result. The term 'crop drier' generally applies to the heater, its controls and a fan. These various units are combined into one package. The complete unit may be stationary or it may be portable.

There are two general types of crop driers -- The direct fired, and the indirect fired. In the case of the direct fired drier, the products of combustion pass directly into the product being dried. With the indirect fired type drier the combustion takes place inside some type of metal enclosure known as a heat exchanger. The drying air passes around the outside of this metal enclosure and absorbs heat from it as it passes over the surface. The products of combustion are passed to the outside through stacks.

Most of the crop driers available today burn either fuel oil or LP gas. The direct fired type driers, since the products of combustion pass into the material being dried, are somewhat more efficient than the indirect type, but it is generally considered that the indirect fired driers are somewhat more fire-safe, because there is little chance of sparks being blown into the product. It has been my observation that today most of the direct fired driers being sold use LP gas as fuel. However, several oil fired units are available and in use. It is a fact that oil is considerably harder to burn than LP gas and when using a direct fired drier, consuming oil as a fuel, it is very essential that a careful check be kept on the burner. If it is allowed to get out of adjustment a considerable amount of soot, unburned oil or objectionable fumes may be discharged through the product being dried, thus contaminating it. The formation of carbon in such driers of course creates quite a fire hazard. If the burner and draft control are kept in good working order the combustion efficiency is good and little, if any, difficulty should be experienced.

Since LP gas is easy to burn, such difficulties are usually not experienced. Since little, if any, carbon is formed in burning LP gas, the fire hazard is negligible, provided of course good housekeeping practices are used. Most of the indirect fired driers, commercially available today, burn fuel oil. Either type of drier, burning either fuel oil or LP gas, must have adequate safety controls. There must be a control to protect against the temperature becoming too high, and another to shut off the fuel in case the flame goes out. On the high capacity heated air driers it is also highly desirable to have automatic temperature control. Many of the high capacity LP gas fired units today also use a modulating type of temperature control. Such a control is highly desirable as it maintains a very uniform temperature.

There are basically three methods of bringing the drying air and the crop to be dried together. They are:

1. Deep-bin or bulk drying
2. Batch drying
3. Continuous drying

There are many different types of batch driers. As the name implies, when using a batch drier the entire drier is filled to capacity with the product to be dried. The drying is then started and continued until the entire batch is completed. The drier is then unloaded and refilled.

In many cases round steel grain bins have been used as containers in batch drying set ups. These bins have been equipped with unloading augers in the bottom and have perforated floors. The grain is usually piled in the bin to a depth of two feet or less and leveled. The hot air is then forced into a plenum chamber underneath the perforated floor and passes up through the grain and out the top of the bin. The bins are filled by means of a portable elevator and emptied by means of the auger in the bottom which discharges the grain into a portable elevator transferring it back to a truck, if the grain is to be sold right away, or into a storage bin, if it is to be held on the farm. When using heated air for drying it is essential that the product be cooled to atmospheric temperature after the drying is completed, before the grain is put into storage.

Another type of batch drying that is used quite extensively in some areas is known as wagon drying. With this method of drying, a number of wagons are equipped with perforated floors over some type of plenum chamber. The heated air crop drier is connected to a number of these wagons through an air distribution duct from which flexible canvas ducts go to each wagon.

When using heated air for crop drying, to obtain satisfactory capacity, it is necessary to expose at least 200 bushels of corn or grain at a time. It seems that before the crop starts to give up its moisture at a fast rate, it is necessary to first warm it up. If the amount of grain being dried at one time is too small for a given size drier the capacity will be greatly decreased. Experience indicates that when drying shelled corn with heated air, the batch should consist of at least 200 bushels and apparently no additional capacity is gained when the batch exceeds around 400 bushels.

In view of this it is felt that any wagon drying installation will require at least four wagons. Two wagons should be filled and dried simultaneously while the other two are being filled. Drying on wagons eliminates one handling of the grain. The wagons can be used to collect the corn from the combine in the field. It is then pulled to the drier location and after the grain is dried it can be transported to the storage bin or to market. It is this feature that has appealed to a number of operators. All other types of batch drying set ups require one additional handling of the grain. Most operators do not consider that this extra handling is much of a disadvantage provided that adequate grain handling equipment is available.

Today the most popular type of batch drier is the column type. As the name implies it consists of a column of grain around a central air chamber. In some cases there are two columns of grain with an air chamber between. In others, the column of grain completely surrounds the air chamber. The thickness of the grain column varies from about 14 inches to as much as 24 inches.

Our experience indicates that 18 inches is about optimum. If the column is too thick the drying will be uneven. If the column is too thin the utilization of the drying air will be reduced. An 18 inch thickness results in good drying efficiency and the uniformity of drying is satisfactory.

These batch bins are available with various grain handling and drying arrangements. They may be stationary, semi-portable or completely portable.

The simplest of these batch drying bins has an unloading auger in the bottom for emptying the grain after it is dried. Portable elevators are used to fill it. The bin is equipped with skids making it possible to move it around the farmstead. A portable crop drier connected to the bin with a flame proof canvas duct supplies the hot air for drying. The side walls of the bin and the walls of the air chamber are perforated.

Additional handling equipment such as a receiving hopper, vertical auger, and grain distributing devices are available as optional equipment. Wheels, axle and tongue assembly are available to make the bins completely portable.

Many farmers in addition to growing corn and small grain produce hay. By using a batch bin and a separate portable crop drier, he has equipment that can be used to dry all his crops.

Farmers who have only shelled corn and small grain to dry seem to prefer the completely mobile batch drying units. Such a unit consists of a batch bin, hot air unit, grain handling equipment, and wheels as a single unit completely portable. These units are very popular among custom operators.

Some of these column type batch bins are so equipped that the operator can re-circulate the grain as it is being dried. This results in more uniform drying. Many farmers planning to purchase drying equipment for shelled corn and small grain have a number of round steel grain bins. Frequently they insist on drying 4 feet or more corn or grain in these bins. Since heated air drying in thick layers does not give good results, they have been advised against it. Their argument for drying in these bins are good. They already

have the bins and they would serve a double purpose, that of a drying bin and a storage bin.

As a result of such demands our company has developed and placed on the market a recirculating grain drier for use in such bins. This drier consists of a cone shaped, perforated floor; central vertical auger; spreader; grain baffles; and an unloading spout. It is used in conjunction with a portable heated air crop drier.

This is how it functions. Approximately 400 bushels of shelled corn or grain is put in the bin using a portable elevator. The vertical auger is started at the same time the drier starts. It operates throughout the drying period. Grain next to the perforated floor gets warm and dries first. With the center auger operating, the warm dry grain next to the perforated floor flows into it. The auger carries this grain up to the spreader in the top of the bin which throws it out to the bin wall on top of the wet grain. Wet grain replaces the dry grain next to the floor. Two circular baffles prevent the surface grain from feeding the auger, thus forcing the warm dry grain to slide along the floor to the auger intake. This constant recirculation equally exposes all the grain to the hot air and reduces it to uniform moisture content. After the grain is dried and cooled the bin is emptied by opening a valve in the unloading spout and operating the auger. When all drying is completed the bin may be filled and used for storage.

Continuous driers are in many ways similar to batch driers in appearance. A drier of this type usually has a hot air or drying compartment and a cold air or cooling compartment. The hot air is supplied by a unit similar to that used with batch driers. The cooling air is supplied by a fan. The grain being dried moves continuously through the unit by gravity or conveyors. The rate of travel must be very accurately controlled so that the grain dries to the proper moisture content.

Such driers are being used extensively by elevators or grain dealers. As yet very few are being used on farms. They are usually higher in initial cost, stationary, and require much more skillful management than batch driers.

Generally speaking the time of exposure of the grain to drying air is less and the air temperatures higher in continuous than in batch driers. Many times the operator in an attempt to increase the capacity of the drier will increase the temperature and speed up the flow of grain. Apparently this results in drying the surface of the grain leaving the interior of the kernel high in moisture. Some moisture testers measure primarily the surface moisture of the grain kernels and might indicate that the grain was dry enough for safe storage. After the grain is in storage for a few days the moisture redistributes through the kernels. Then the same moisture tester will show an increase of 2, 3 or even $\frac{1}{4}$ in moisture content. The operator immediately concludes that he is unable to safely store artificially dried grain.

Many elevator operators have insisted that it was not possible to keep artificially dried corn because it picks up so much moisture in storage. After checking their drier operation it is my opinion that they were experiencing the trouble just described. The corn was not dry when it left the drier.

I have not heard of similar difficulties encountered in using batch driers. We recommend that farmers and many small elevators use batch driers. Some continuous driers can also be operated as batch driers.

One question that is frequently asked by farmers who are considering purchasing drying equipment is, 'At what temperature should my corn be dried?' At the present time there seems to be considerable confusion among the authorities concerning the answer to this question. It is generally accepted that 110° Fahrenheit is safe for grains to be used for seed purposes. Mills, which produce starch, corn oil and gluten feeds, at the present time will not buy grain known to be artificially dried. Unless grain is dried at temperatures around 130 to 140° the grain does not process properly. Most authorities agree that for corn that is to be used for feed, rather high temperatures may be used. I have observed several statements to the effect that the feeding value of grain is not hurt by drying, except that over-heating can decrease palatability. What is meant by over-heating is not too clear. Just recently the Crop Dryer Manufacturers Association made some recommendations regarding drying air temperatures for various grains. For drying shelled corn, these recommendations are as follows:

"Corn that is to be sold for commercial use ----- 130° F.
Corn that is to be used for animal feed ----- 180° F."

When heated air is being used, we are faced with the ever present possibility of fire hazard. The higher temperatures developed by the drier naturally increases the fire hazard. It has been our experience that when corn is dried at temperatures around 150 and 160° it is practically impossible to tell the difference between it and naturally dried corn. If the drier is equipped with a fan that is delivering a good flow of air a drying temperature of 160° will give all the capacity that most any farmer needs to handle the grain from one picker sheller or one corn combine.

Table No. II presents some information showing the drying capacity of a batch drying set up equipped with a 7½ H.P., 42" fan and an LP gas burner. You will note that with a drying air temperature of 160°, this drier with a heat output of 2,000,000 BTU's per hour will dry corn at the rate of 100 to 120 bushels per hour.

In checking the harvesting capacity of most machines available today, I find that farmers, who have corn that will yield 80 to 100 bushels per acre, think in terms of being able to harvest 800 to 1000 bushels per day. This harvest rate more or less sets the drier capacity which they should use. From this it seems that a drier which will handle 100 bushels of 25% moisture content corn per hour and dry it to 12 or 13%, should be quite satisfactory to harmonize with the harvesting equipment.

For a farmer who does not wish to invest in a drier of this capacity, it is well to remember that with a drier it is possible to start the harvest earlier in the season, so that the rate harvested per day does not need to be quite so high. The harvesting can be spread out over more days. Also it is possible to run the drier several hours longer per day than the harvesting equipment is operated, should it be necessary.

TABLE NO. II

EXAMPLE OF DRYING AIR TEMPERATURES
RELATING TO DRYING CAPACITY

FUEL ----- LP Gas

BATCH BIN CAPACITY ----- 400 Bushels

INITIAL MOISTURE CONTENT SHELLLED CORN 28%

FINAL MOISTURE CONTENT SHELLLED CORN 13%

AIR OUTPUT OF DRIER (CFM) ----- 20,000

AVERAGE TEMPERATURE OUTSIDE AIR -- 65%

AVERAGE RELATIVE HUMIDITY ----- 50%

FAN MOTOR H.P. - $7\frac{1}{2}$ H.P. ELECTRIC

<u>Drying Air Temperature</u>	<u>BTU/hr Output</u>	<u>Moisture Load (lbs)</u>	<u>Bu. Per Hour</u>	<u>Cost Per Bu. Gas & Electricity</u>
130°F	1,404,000	4680	85	2.9¢
140°F	1,620,000	4680	93	3.05¢
150°F	1,836,000	4680	108	2.9¢
160°F	2,052,000	4680	120	3.0¢
170°F	2,268,000	4680	136	2.9¢

Another question which several farmers bring up is, 'What type of power should I use?' It has always been our policy to recommend the use of electric power wherever possible. It is more convenient and satisfactory to use, where the drying equipment can be set up at a centralized location, near a power supply. Electrical power is quite flexible and since controls are a necessity on drying equipment, electricity will probably be the most economical in the long run. However, in many areas there is the problem of transformer and line capacity as well as the capacity of the wiring system on the farm to meet the power requirements of the drying equipment. The power suppliers' agricultural engineers or rural representatives may be contacted when drying equipment is being considered to see whether or not there is available power to handle the installation.

In case electricity is out of the question, driers can be equipped with gasoline engines or power take off drive for the tractor operation. A generator can be added to supply the electricity to operate the fuel pumps and electrical controls. When a tractor or gasoline engine is used, it is going to require very close attention to keep the tractor or engine fueled, properly lubricated and attended. When a tractor is used to operate this type of equipment, it operates at only a fraction of its capacity, and for this reason it is relatively inefficient. In many cases at this time of the year, all of the tractors that the farmer owns are needed in the harvest operation and in transporting the grain from the field to the barn or to the drying location. Never-the-less, today many of the large batch driers are being operated by tractors. I would like to emphasize again that there is a wide variety of sizes and types of drying equipment available to fit practically every possible need.

THE HEAT PUMP FOR CONDITIONING CORN

by

Chester P. Davis, Jr., Agricultural Engineer
Agricultural Engineering Research Branch
Agricultural Research Service, U. S. Dept. of Agriculture

The basic system utilized in conditioning air for grain drying with the heat pump is practically identical to that provided by the refrigerant-type dehumidifier with which most of you are acquainted.

Schematically shown (Figure 1), moisture-laden air leaving the drying grain is circulated over the cold evaporator coil of the refrigerant system. The air is here cooled to and below its dew point, the moisture condenses out and is removed from the system. This dehumidified air is now passed over the refrigerant condenser of the system where it is reheated. The heat added consists of both latent and sensible heat extracted at the evaporator and work energy released in the form of heat by condensing unit operation. Location of the blower following the evaporator rather than as shown here would make more of that additional work energy available for drying.

Considering conservation of heat from a basic thermodynamic standpoint, it appears this system is difficult to excel as the heat in the system is continuously reclaimed for use in further drying. To the contrary, in the conventional heated-air drier, the heat added to the air is "expended" after passage through the grain mass where drying occurs.

Theoretical study (1, 2) of the feasibility of using the refrigerant air dehumidification process for grain drying was undertaken in the fall of 1947. In 1948, a system employing this same principle was designed and built at Princeton Farms in Indiana. This system shown in Figure 2 was used in conditioning popcorn to a 13.5% W.B. moisture content, which is the optimum condition for maximum popping volume. By suitable refrigerant system design, and airflow and refrigerant control, the drying air temperature and relative humidity could be regulated to provide air that would be in equilibrium with the grain at the final moisture content desired. An air temperature and relative humidity of 85° F. and 70% R.H. respectively were used for drying. In the spring of 1949, Mr. George Foster and I (3) observed the unit and conducted an analysis of operation. It was not drying as evenly as it had been hoped it would. This analysis revealed that uneven drying was due to the unequal air distribution in the drier and was not due to the fundamental drying cycle. Recommendations for correcting these conditions were made. Satisfactory operation resulted for the drier has been utilized regularly since that time. In a recent exchange of correspondence, this was substantiated by Mr. Dan Pieper, Production Manager, in charge of operations at the Farm.

Completion of theoretical studies showed, as indicated in Figure 3, that the power requirement for dehumidification was greater for conditioning air to a low relative humidity than that required for producing air at a higher relative humidity. This is true as a lower evaporator temperature is necessary to produce the low humidity air. You will recall that the lower the evaporator temperature and/or the higher the condensing temperature, the greater

are the energy requirements for mechanical refrigeration equipment of a given capacity. As you would expect, however, the drying capacity of the two differ and more air must be circulated to provide drying with high humidity air. At a specified rate of drying, this means more blower power is required. Theoretically, there is approximately a total equal power requirement at approximately 4.5 ft. of depth for the test conditions studied. This was for an airflow of 30 c.f.m./bu. Figure 4 shows these requirements translated into costs and kwhr electrical energy per bushel for reducing the moisture content from 25 to 13.6% dry basis.

In 1952 USDA and the Agricultural Engineering Department (4) at Kansas State College cooperated in building a laboratory-type experimental drier using shelled corn for the tests, (Figure 5.). Each section was 4' x 4' x 4' in dimension with multiple sections fitting together to give greater grain depths. The series of tests run with this drier was designed to experimentally confirm parts of the theoretical study previously made. Temperatures and relative humidity of the air during a typical test are shown in Figure 6. The air temperature entering the grain rose steadily during the first 15 hours and then held steady until midway in the test. After that point it decreased. This decrease was due to an outside ambient air temperature drop which influenced the system temperature. This points up one of the characteristics of this system. The only heat being added is that due to the heat equivalent of work energy provided. If this is allowed to escape by transmission or other loss, then the system temperature necessarily drops and the drying potential and efficiency does likewise.

Figure 7 shows the layer drying rate curves and the rate of moisture removed. This is a fairly normal drying pattern and indicates the warmup period of the grain and system to the maximum level after approximately 20 hours. It can be seen that there might be some advantage to using a supplemental source of heat initially to boost this to more favorable operating temperatures early in the drying period.

This laboratory test was followed in 1953 by drying milo on a field scale using 500 bushels in a 1000-bushel steel bin (Figure 8). The bin walls were later partially insulated. A 3-horsepower heat-pump dehumidifier and blower was used. Results confirmed generally those obtained with shelled corn. Slightly higher energy usage per pound moisture removed was experienced as there was greater heat losses from the system and more blower power required.

Both series of these tests were conducted using grain of a fairly low initial moisture content, 16 - 17.5%, and a perhaps lower than required final moisture content of 11.5 - 13% (dry basis). Low rates of airflow, 6 c.f.m./bu., over a 48 - 72-hour drying period were used. These initial and even lower percentages of moisture have been found in the field regularly as early as late September in the past three years in some corn-producing areas. This, however, is not the normal or average situation for year after year operation throughout the corn belt, particularly in our consideration of picker-sheller harvesting.

With higher initial moisture conditions in mind and with the additional objective of more rapid drying, the Agricultural Engineers at the University of Minnesota (5, 6) conducted a series of tests using shelled corn of initial moisture contents in the range of 27 to 38% and airflows of approximately 30 c.f.m. Figure 9 shows drying under these conditions and compares it with the drying tests earlier mentioned. Electrical energy requirements (kwh/lb.) for removal of moisture proved to be less for the Minnesota tests. This might have been predicted and was due largely to the much greater initial moisture content. The first part of the drying period was therefore in a higher portion of the falling rate drying period.

The energy requirement to remove one pound of moisture had been computed from early theoretical considerations to be 0.125 kwhr. This value was not fully realized and laboratory results showed 0.15 to 0.20 kwhr. There was heat leakage from the system through transmission that would explain at least some of this difference, so that it could be stated that theory and pilot plant results in general coincided within the limits of experimental error. Drying temperatures of 100° - 130° F. were employed with greater drying efficiencies demonstrated at the higher values.

Applying the appropriate rate per kwhr for electricity, e.g. a 2¢ rate, the operational costs were 0.3 - 0.4¢ per pound of moisture removed.

It is difficult to obtain completely comparable comparisons with drying using fuel-fired equipment, but experimental tests conducted by George H. Foster (7) indicate the cost to vary between 0.4 - 1.4¢ with an average of 0.81¢. Admittedly his tests were for a low average moisture removal (1.4%) and at a relatively low moisture content level (14.8 to 13.4%). Similar tests with the heat pump at these levels showed energy requirements averaging 0.4 kwhr.

Use of preheat to reach optimum drying temperatures more quickly has been considered, as previously mentioned, and a 5 - 10% decrease in energy consumption has been found theoretically possible. Whether system complications and extra equipment necessary to provide preheat would be justified is debatable at present.

In considering this method of drying, the disadvantages of the dehumidifier should be enumerated. They are:

- a. An insulated, vapor-tight system is essential for maximum efficiency. A steel bin would not be suitable but in combination with a portable batch drier might well be employed for storage with handling to and from the drier as required.
- b. A five horsepower unit is capable of conditioning a batch of approximately 135 bushels from 30% to 13.6% (dry basis) in a 24-hour period. For rapid harvesting on the average farm, where electrical service capacity is at about that level, this might be a significant limitation. Three-phase power or other power sources would allow adequate capacity.

- c. First cost and maintenance for equipment of this type would probably exceed that for oil or fuel-burning driers, though no factual information on this is at present available.

In general, the following advantages of the closed-cycle heat-pump dehumidifier for grain drying may be cited:

- a. In a closed-air cycle, drying is independent of outside air conditions except as previously explained.
- b. Heat can be added to the circulated air with virtual elimination of the fire hazard.
- c. Dual temperature and humidity control is possible for specialized conditions such as are desirable in popcorn drying. Seed corn, rice, grass, legume, and other special seeds might well be other such cases.
- d. The drying equipment does not need frequent attention during operation.

Though these advantages of the heat pump may outweigh the probable savings in fuel or energy costs in importance, such savings are an active possibility.

Theoretical study and research have demonstrated feasibility. While general specifications for such a batch unit of 200-bushel capacity (5) have been prepared commercial development is not yet in sight. This would seem fully justified on the basis of research to date.

BIBLIOGRAPHY

1. Davis, Chester P. Jr. - Possible Farm Applications of the Heat Pump, *Agricultural Engineering*, pp. 323-325, May, 1953.
2. Davis, Chester P. Jr. - A Study of the Adaptability of the Heat Pump to Drying Shelled Corn, unpublished master's thesis, Purdue University Libraries, June, 1949.
3. Foster, George H. and Chester P. Davis, Jr. - Report of Test Observations on the operation of a Heat Pump Drying Installation at Princeton Farms, unpublished report to Purdue Agricultural Engineering Department and Farm Structures Section, AERB, USDA, March, 1949.
4. Shove, Gene Clere - A Laboratory Investigation of the Adaptability of the Heat Pump to Batch Drying of Shelled Corn, unpublished master's thesis, Kansas State College Library, June, 1955.
5. Cloud, Harold A. - Existing and Projected Research on Uses for Heat Pumps on Farms, unpublished paper presented at winter meeting of ASAE, December 6, 1954.

6. Cloud, Harold A. - A Study of the Possibilities of Heat Pump Applications in Agriculture with Recommendations for Research, Report No. 555, American Gas and Electric Service Corporation, November 15, 1954.
7. Foster, George H. - Methods of Conditioning Shelled Corn, Agricultural Engineering, pp. 497, October, 1950.

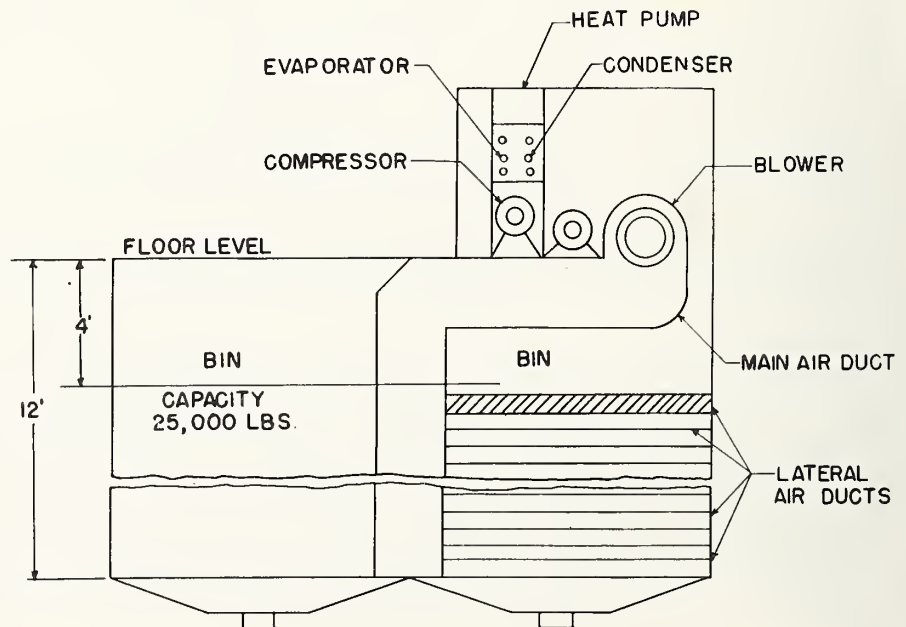
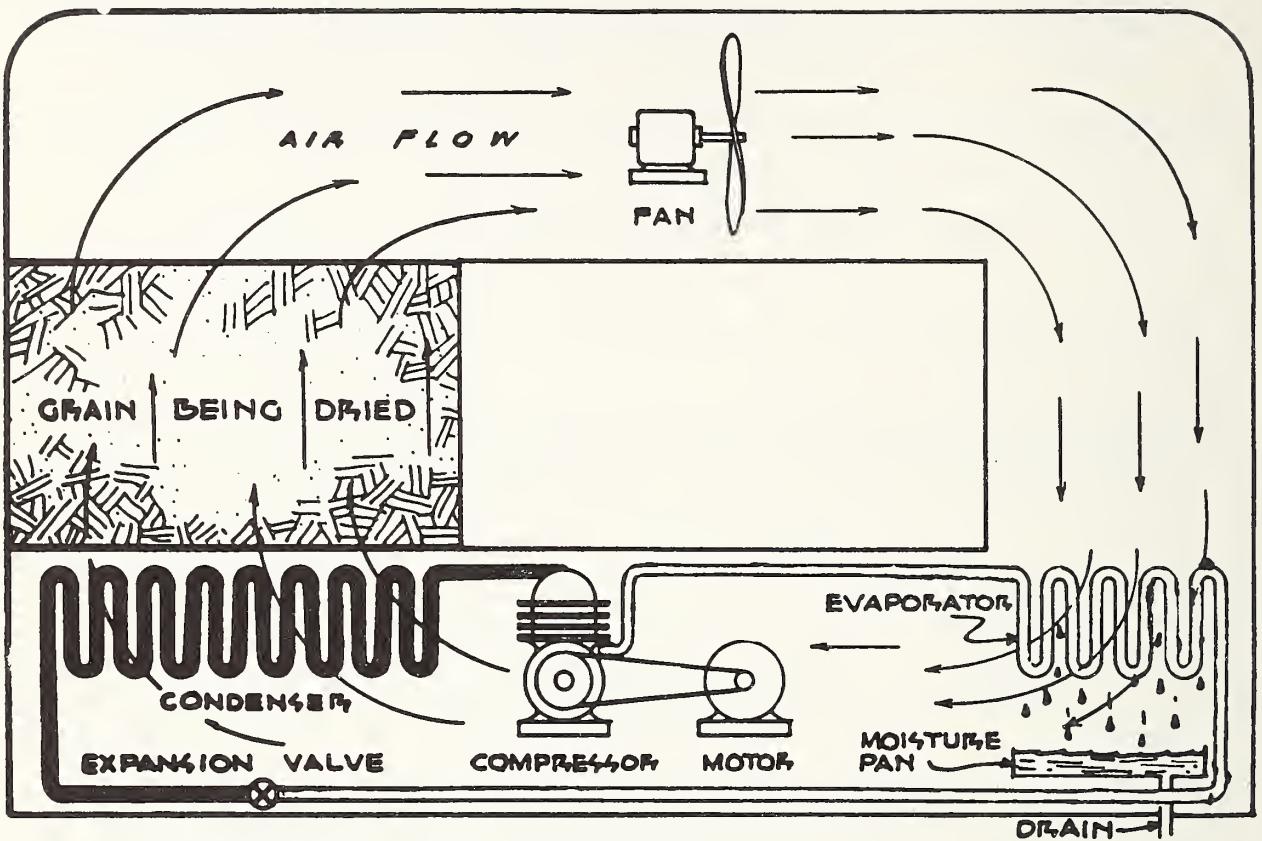


Figure 1.--Schematic diagram of a heat pump grain drying system.

Figure 2.--Heat pump popcorn conditioning system.

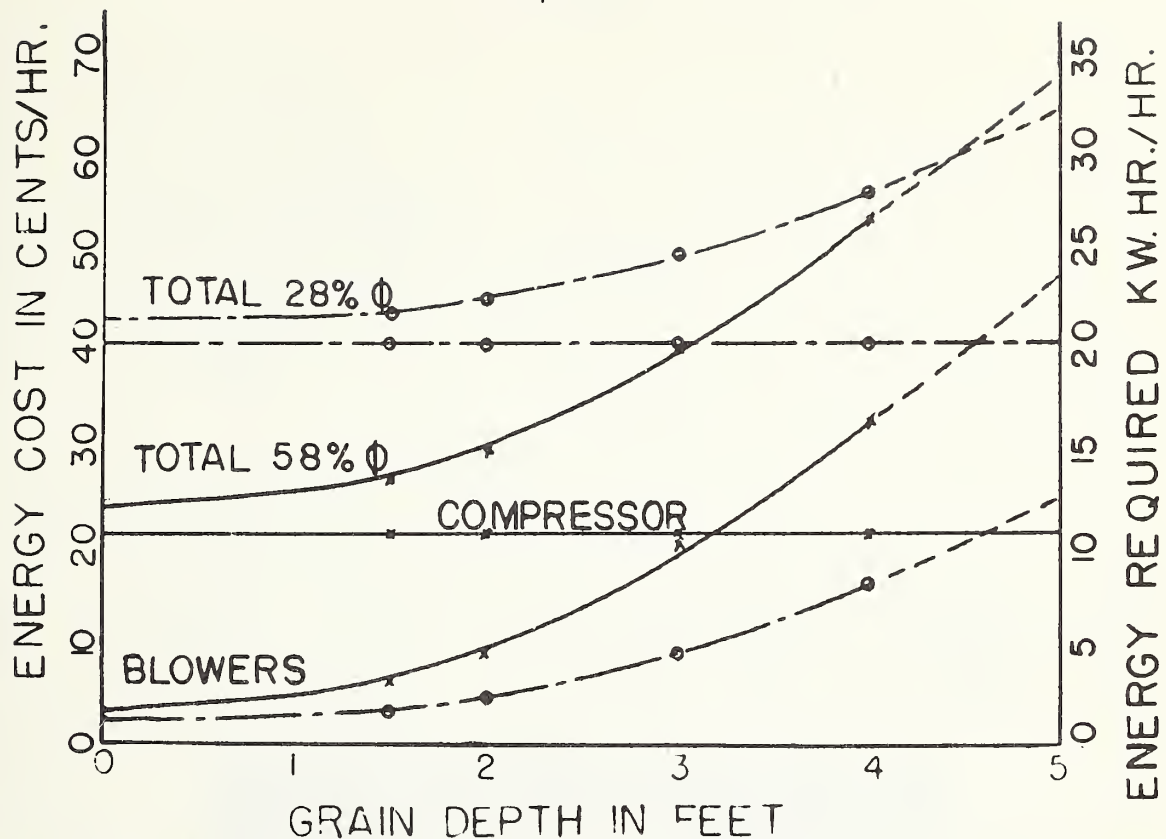


Figure 3.--Energy Required for Operating Continuous Type Shelled Corn Drier at 110°F. and at a rate of 1000 lbs./hr. (25-13.6% D. B.)

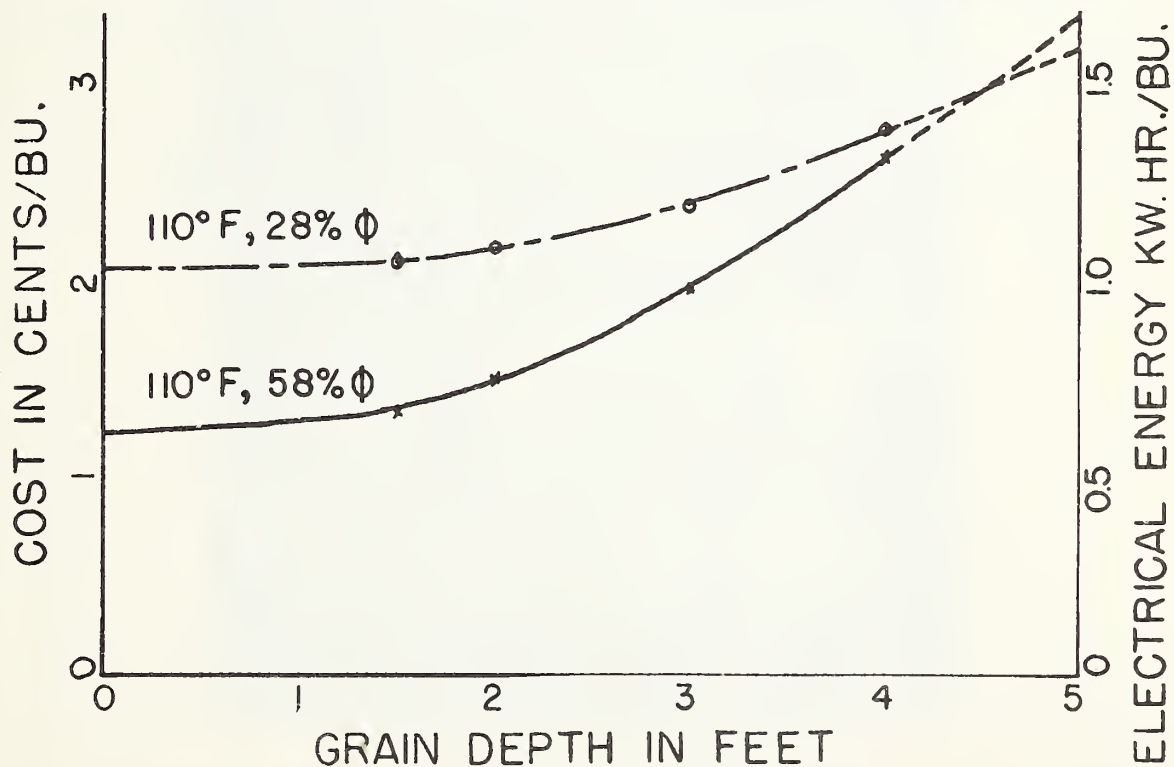


Figure 4.--Energy Required and Cost of Energy / bu. for operating Continuous Type Shelled Corn Drier. 1000 lbs. grain dried / hr. (25 - 13.6% D. B.)

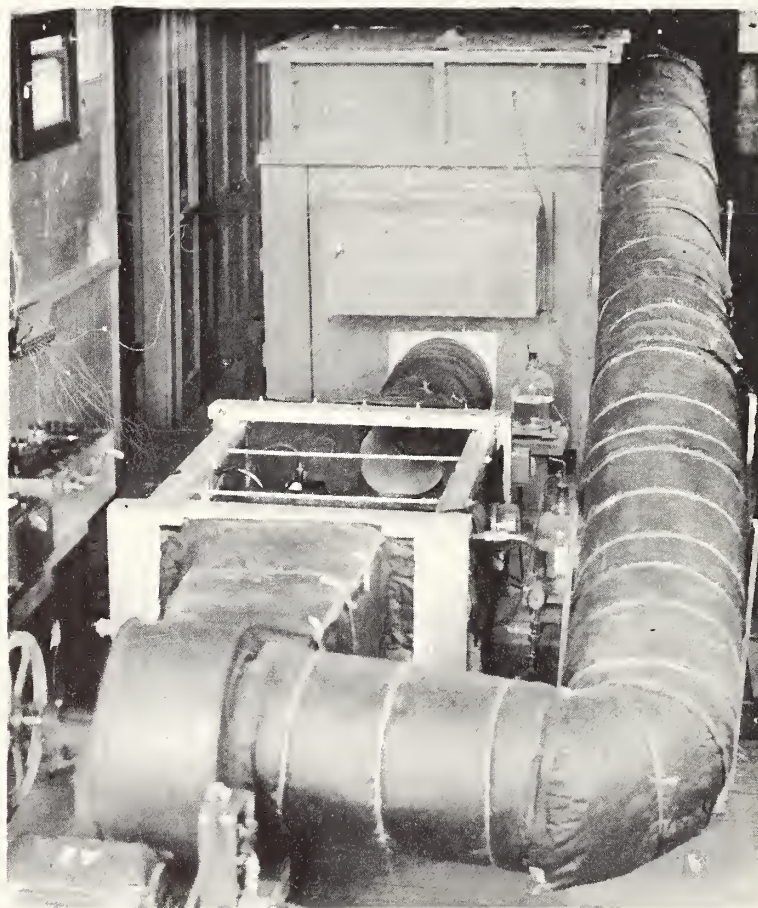
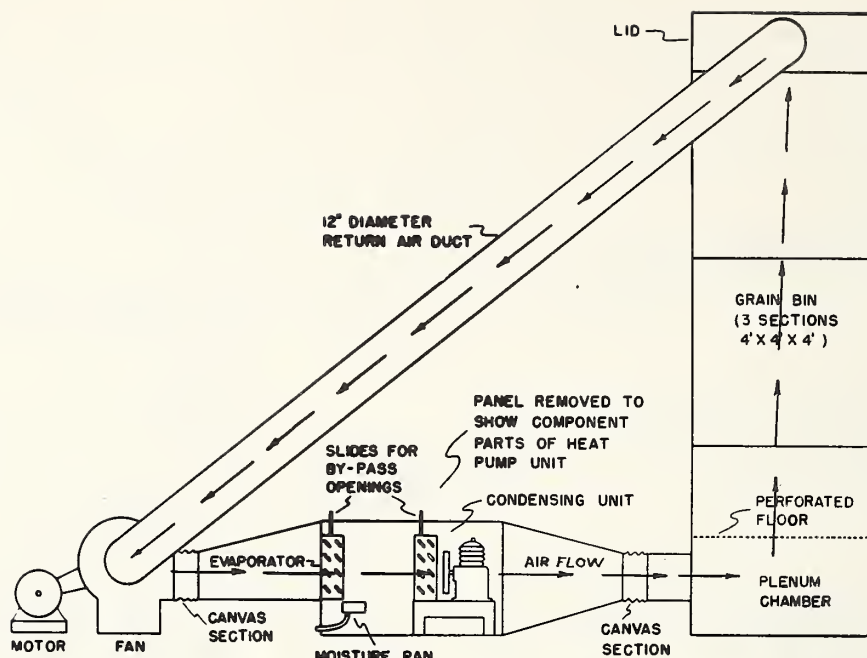


Figure 5.--(Top) a. Scale drawing of an experimental recirculated air heat pump grain drying installation.
(Bottom) b. Photo of above drier.

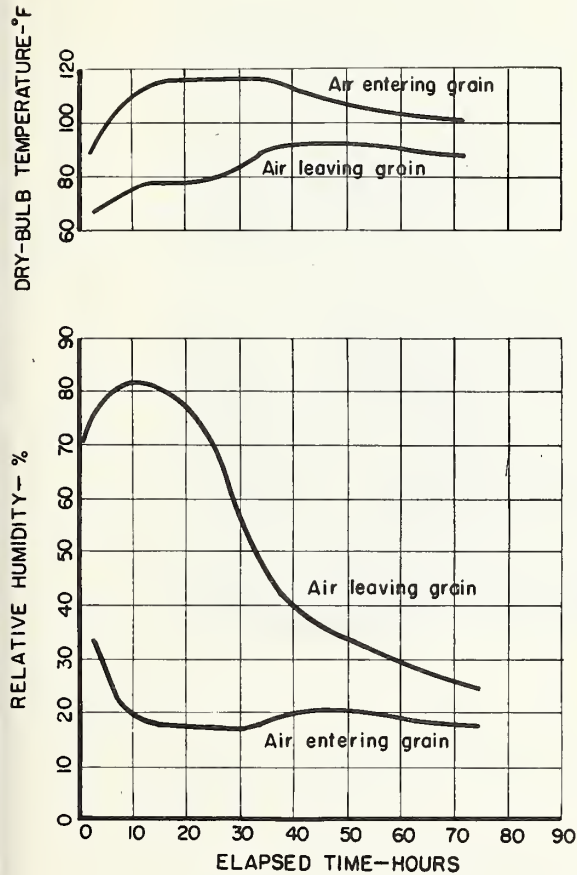


Fig. 6.--Temperature and relative humidity of air during Test No. 4.

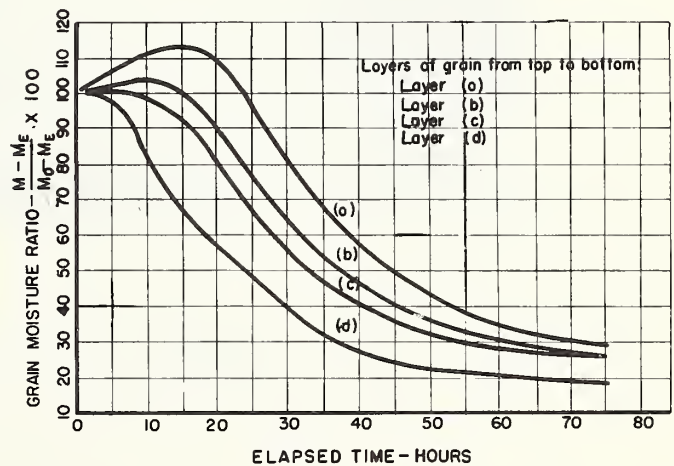
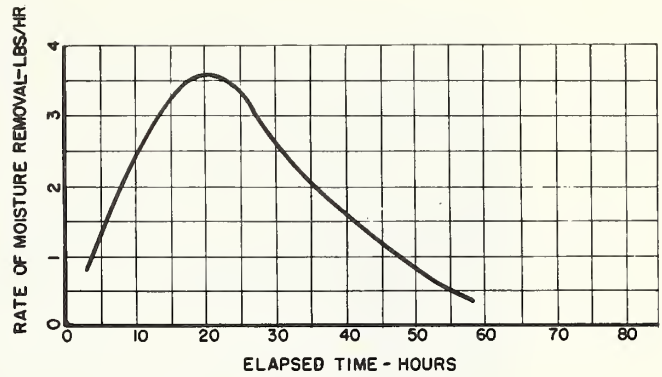


Fig. 7.--Drying rate curves for Test No. 4.

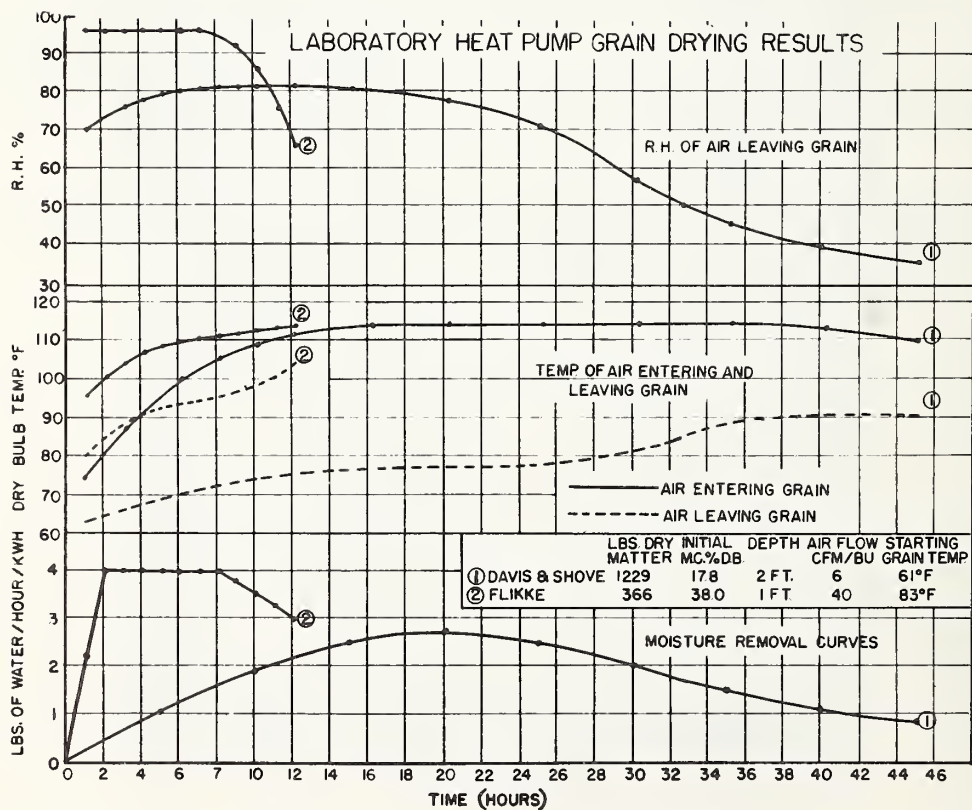


Figure 8.--Experimental heat-pump installation for drying milo in a 1000 bu. steel bin.

Figure 9.--Results of laboratory drying of shelled corn.

CONVERSION OF FACILITIES FOR STORAGE AND HANDLING OF SHELLED CORN

by

E. A. Olson, Agricultural Extension Engineer,
Department of Agricultural Engineering,
University of Nebraska, Lincoln, Nebraska

Most farmers are aware of the rapid developments taking place in the techniques of harvesting, drying, storing, and handling of shelled corn. They realize that in the near or immediate future, some of these changes must be adopted as a part of their farming operation.

Field shelling of corn will ordinarily be done with the moisture content ranging from 20 to 28%. Therefore drying of the "wet" corn will be necessary unless it is stored in an air-tight glass-lined silo. In the process of planning for field shelling, drying, and storing of shelled corn, the farmer must make a careful study to determine whether he will use heat or natural air for drying. When heated air is used the depth of grain in storage will not ordinarily be a factor since the batch or continuous-flow dryer will be used to remove excess moisture. But with natural air, drying will take place in storage. Since depths in excess of eight feet are not considered practical for natural air drying, this factor must be considered in adapting buildings for storage of shelled corn. In some instances after an eight foot depth of corn has been dried, additional dried or nearly dry corn has been added to utilize the full depth of storage. If corn with excess moisture is placed in the storage, on top of dried grain, depths of 10 feet ordinarily should not be exceeded.

Buildings That Might be Adapted for Shelled Corn.

Anyone connected with agriculture realizes that farm income has been declining more over the past few years. Farmers can help reduce cash expenditures by conversion of existing buildings where economically feasible for shelled corn storage. Buildings that can be adapted for storing shelled corn include the following:

- a. Cribs of various types of construction (wood, concrete, and metal).
- b. Tight wall grain storages (wood and metal).
- c. Barns and other buildings.

Before considering the conversion of existing buildings, let us review the basic requirements for storing shelled corn. First, the building has to be strong enough to hold the shelled corn which exerts about three times the pressure of ear corn. The floor should be moisture proof, while the walls and roof must be weatherproof. If the storage is equipped with a drying system the walls and floor must also be reasonably air tight to reduce air leakage. Ease of filling and emptying are also very important in this day of automation.

Structural Problems of Adaptation.

In adapting a building for shelled corn storage all structural problems must be considered to help determine if conversion is economical. Only after these

factors have been considered can the farmer make a sound decision. Most important is the basic structure and condition of the building. Old horse barns with a timber frame, even though structurally sound, would require nearly as much structural framing as a new storage.

Many buildings do not have foundations adequate for grain storage. Side wall pressure of the corn on the wall becomes a vertical load on the foundation and footing. If wood floors are supported above grade, spread footings with one square foot for every fifty bushels of stored corn will be needed. With concrete floors on suitable grade, footing requirements drop considerably and will vary with the depth, and size, of storage and soil condition. Foundation walls should extend at least eighteen inches above grade. Information for determining foundation requirements will be found in the Agricultural Engineering Yearbook.

Floors can be of concrete or wood. Frequently concrete is used because of economy and rodent protection. For moisture proof construction, a well drained site is important. First, a four to six inch fill of coarse material (gravel, crushed rock or cinders) should be placed. This is followed by a grout, which is covered with a vapor barrier such as two layers of asphalt roofing, lapped and mopped with hot asphalt. Finally a four inch layer of good quality concrete, properly mixed and cured will provide a durable floor.

Walls of most existing buildings such as cribs or barns will need to be strengthened or reinforced to withstand grain pressures. Wall studs should be secured to the concrete floor or sill with some of the types of stud fasteners now available. In old horse barns the lower end of the stud may need to be cut off unless it is in good condition. When this is done it may be most practical to remove the same amount of the lower wall covering and set the building down on the foundation.

Strengthening of walls can generally be done with horizontal steel rods placed laterally and lengthwise of the storage. Rods $\frac{3}{4}$ or $\frac{7}{8}$ inch will need to be placed about 4 feet apart and at a height of 6 to 8 feet to facilitate emptying and cleaning storages. To transmit wall pressures to cross-ties, horizontal timbers or "waling strips" of 4 x 6 or 6 x 6 material must be placed on the outside of the building wall. Exact requirements will depend on storage depths and bin sizes.

Various means of providing grain-tight and weather tight walls can be used. While it is not recommended, the first impulse when restoring old cribs is to install a lining on the inside of the studs with a weather tight covering placed over cribbing. This method has some structural advantages; however, with a lined wall grain storage, rodents and insects are almost impossible to control. Our entomologists do not recommend this procedure because of the problems it creates. If cribbing is left on the crib walls it offers an excellent ledge for shelled corn or other small grain to lodge, forming a harbor and breeding place for grain insects. We recommend the removal of cribbing. If the cribbing is beveled and in good condition, it can be replaced with the outside face nailed to the studs to help prevent grain from lodging in the crack between boards. When cribbing is in poor condition, replacement with shiplap or grain tight siding would be advisable. In either case a double wall will be necessary. The sheathing or cribbing should be covered with building paper and a weather tight covering of metal, wood, asphalt, or other siding material. When all new material is required, the use of exterior grade

plywood may be practical depending on labor and material costs. Regardless of the materials used we must have a grain-tight, weatherproof, air-tight wall to provide for satisfactory long time storage. A wall with a smooth interior surface free of cracks will be easy to clean and keep free of insects.

Most building roofs will be satisfactory if they are weather tight. If roof repair is needed, new roof covering of suitable materials should be applied. When the interior roof supports in the barn are removed, roof truss framing can be done with salvaged floor joists. A typical example will be discussed later.

We are of the opinion that the conversion of old horse barns for grain storage is a very practical method of utilizing these buildings standing vacant on many farms. This type of storage will in most cases give the farmer the type of storage he needs at an economical cost. This type of flat storage lends itself to natural air drying or aeration and can be filled easily with grain elevating and conveying equipment. Multi-purpose use of this type of storage is another attractive feature to most farmers.

Handling and Drying Facilities.

Productive use of farm labor is most important. Buildings being converted for storage should include mechanical equipment for filling and emptying. A variety of elevating, augering, and conveying equipment is available. The selection of stationary or portable equipment will depend on the farming program. With electric power the use of horizontal conveyors or augers provides a practical and economical method for filling flat storages. When storage is divided into a number of compartments this equipment, in conjunction with auxiliary augers, can be used for removing the grain.

On the livestock farm the shelled corn storage may also serve as a feed processing center and for storage and handling of other grain and feed concentrates. Here facilities for grinding, rolling, mixing, and/or weighing and handling prepared feeds are most important. Planning of the storage, whether it is a conversion or a new fabricated structure, should take into consideration the need and use of these facilities. The inclusion of this equipment will help make feed handling automation a reality. The farmer is eager to "retire" the shovel, and as agricultural engineers we can help him accomplish this purpose.

Possible Effect of Clean Grain Program.

We are all familiar with the Clean Wheat Program being enforced by the Pure Food and Drug Administration of the Department of Public Health, Education, and Welfare. While the standards now apply to wheat as a "food" grain, the possible effect of such standards on corn has been studied by a committee appointed by the Secretary of Agriculture. We have no definite information at this time; however, we should be aware of this probability. In brief, we should design and build storages that are rodent proof or that can be made rodent proof. Smooth walls free of cracks and dead air spaces are also desirable to help eliminate insect harbors. If grain standards are changed in the future to allow the operator to sell corn at nine to ten percent moisture content without discrimination, drying to this level may be advisable. Our entomologists have stated that grain at this moisture level with aeration

would practically be free of insect activity. Bird proofing on storages must also be included. This primarily involves screening of windows and other openings.

Typical Examples of Adaptations

Ever since we started a program on crop drying, farmers have expressed interest in the conversion of buildings for shelled corn storage.

Interest developed first in the use of the round metal grain bin. This storage is structurally sound; however, when natural air is used for drying, a duct system must be designed and installed. Here are two examples of this type of storage. Ernest Linner of Phelps County has a steel bin with the duct system built in 1949 which he used for drying shelled corn from an initial moisture content of 27.8%. Where larger quantities of grain are involved, more than one storage may be served by one fan.

Two metal bins may be connected together with a common duct for supplying air to either or both bins using a system of dampers (Figure 1). This is a part of the installation on the O. H. Schuneman farm, one of our Irrigation Development Farms in the Republican Valley.

The use of a flat type steel building was a problem on the Paul Troester farm in Hamilton County (Figure 2a). This building was designed to store grain but built originally for machinery shelter and for a small amount of grain (Figure 2b). In 1950 this storage was adapted with two bins on either side of the drive and overhead storage for a total of 3,000 bushels. These bins were equipped with a duct system for drying shelled corn. Three more bins were added to bring the capacity up to 6,000 bushels of shelled corn harvested with a picker sheller. A second irrigation well and better corn yields created need for more storage. Another flat storage 32 x 48 was added in 1953. At that time the manufacturer of this structure asked Prof. G. M. Petersen of our Department to design the air distribution system. This brought Mr. Troester's system up to a capacity of ten to twelve thousand bushel of shelled corn which he dries with two fans.

Many farmers have a small crib in fair condition for ear corn storage. Such was the case on the Jim Bailey farm in Buffalo County. He replaced the present foundation and built a new concrete floor. To hold shelled corn, ship-lap was nailed to the inside of the studs and a duct system was installed for drying or aeration. This building fills some of the requirements for good storage; however, the present cribbing should be covered to make the building weather tight. Since a dead air space in the wall exists, insect and rodent troubles are likely to develop. Situations of this type show the need for strengthening and intensifying our Engineering Extension Programs. This situation occurred in a county with the Farm and Home Development Program which is adding considerable demand for time of the agricultural engineer.

During recent years we have questioned farmers as to the advisability of constructing new corn cribs. However, our demand for crib plans has been quite high in recent years. New cribs of the Midwest Plan Service design will present less of a problem for remodeling, since the wall studs are anchored at the floor and heavier studs have been used. In a crib on the T. Merton Kuhr farm, in Washington County with 14-foot walls, 2" x 10" wall studs are used in place of 2" x 6" or 2" x 8". Horizontal cross ties and appropriate wall

covering should make this very satisfactory for shelled corn storage.

During the past two to three years we have had numerous requests for assistance in remodeling barns for grain storage. A questionnaire was prepared concerning the structure and structural conditions of the building in order that we might be able to give a more complete answer to the problems. This has proven very helpful and as a result a number of barn remodeling demonstrations have been established in the state. Each building has presented a somewhat different problem and has taken considerable time on our part as well as drafting personnel to prepare this material. Here are two examples of barn remodeling.

Earl Mead of Dawson County who had a good barn standing vacant, converted the mow for storing and drying shelled corn. Floor supports were reinforced, wall studs added and the interior of the mow lined with exterior plywood. The barn, 32 x 30 feet, was divided into four bins $13\frac{1}{2}$ x $15\frac{1}{2}$ and 8 feet deep. An air distribution system, 8 feet high and 2 feet wide, extends thru the middle of the mow the length of the barn to provide access for controlling air flow to each bin. Grain is conveyed to the bins with a portable elevator and is removed through the floor into a small auger and directly to the truck. Mr. Mead used natural air for the first two years but has provided supplemental heat to reduce air humidity as much as 20 to 30 percent by raising air temperature 15 degrees. The cost of materials for remodeling and the air distribution system was under 10 cents per bushel.

Another barn with some interesting possibilities is on the M. W. Webb farm in Buffalo County (Figure 3a). Structurally the barn is in good condition with a fairly new roof, however, the siding needs repair. The barn will be moved to a new location and because of the volume of shelled corn to be stored, it was decided to remove the lower end of the wall studs. The stalls and mow floor will be removed, leaving unobstructed area for grain storage. Material from the lower ends of the studs will be used to truss the side wall (Figure 3b). Lateral pressure from these trusses is carried to the lower chord of the roof truss to hold walls from spreading (Figure 3c). End walls are also trussed as shown, using mow floor joints. Conversion of this building has not been completed as of this date, consequently cost data are not available.

Throughout the Corn Belt thousands of concrete cribs of various types are to be found. From the structural standpoint these storages will hold shelled corn, and are being used by some farmers for storing shelled corn dried with heated air. By filling at the center, leakage of grain is held to a minimum. According to reports, loss due to spoilage at the edges has been negligible. However, for long time storage, some loss is likely through damp seasons. To prevent shelled corn leakage, lining on the inside should be used. By adopting the round storage with a vertical perforated duct, air flow through shelled corn could be controlled with a movable plug located in the vertical duct. To make the storage weather proof an exterior covering will be necessary. We have not tried this system to date, but anticipate the need for this in the near future.

These examples give some idea of how storages can be adapted for shelled corn. It should be pointed out that this step should not be taken until the farmer has made a decision as to the method of harvesting and drying which he will use. The smooth flow of shelled corn from the field into storage for subsequent drying can be accomplished economically with careful planning and sound engineering.



a



b

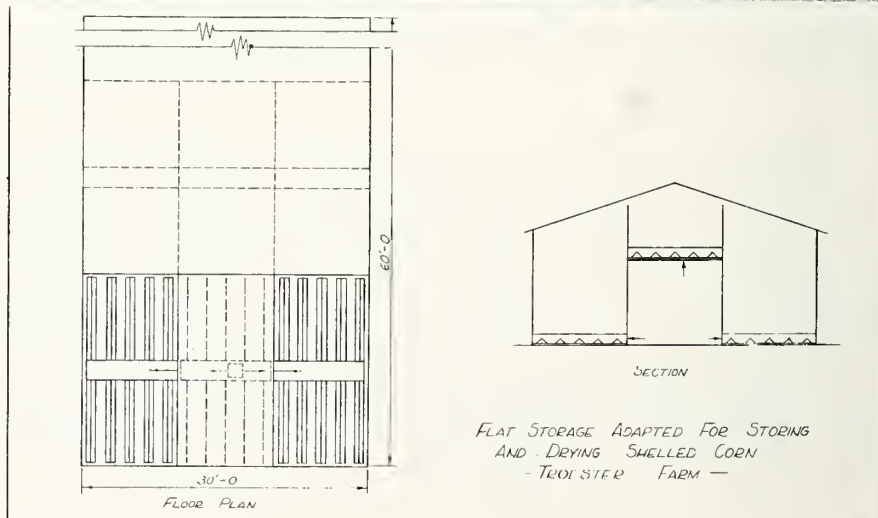
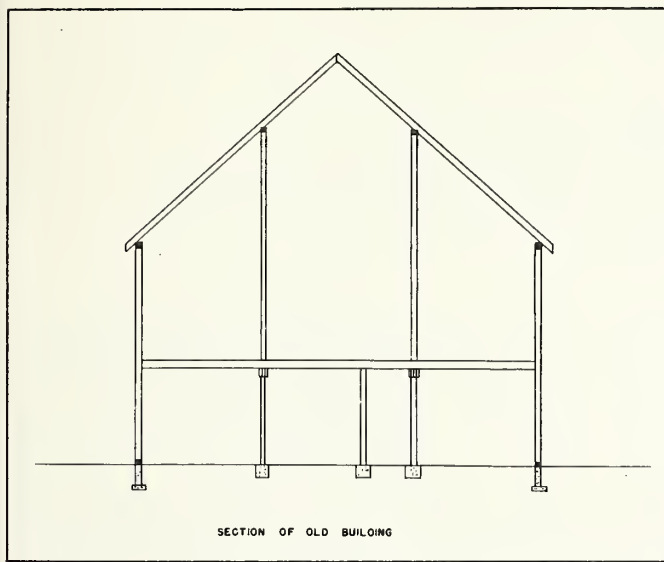
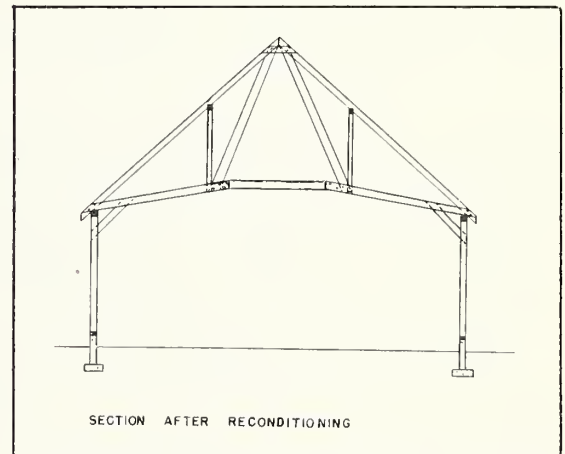


Figure 1.--(Top) Two metal grain bins supplied with drying air from a common duct.

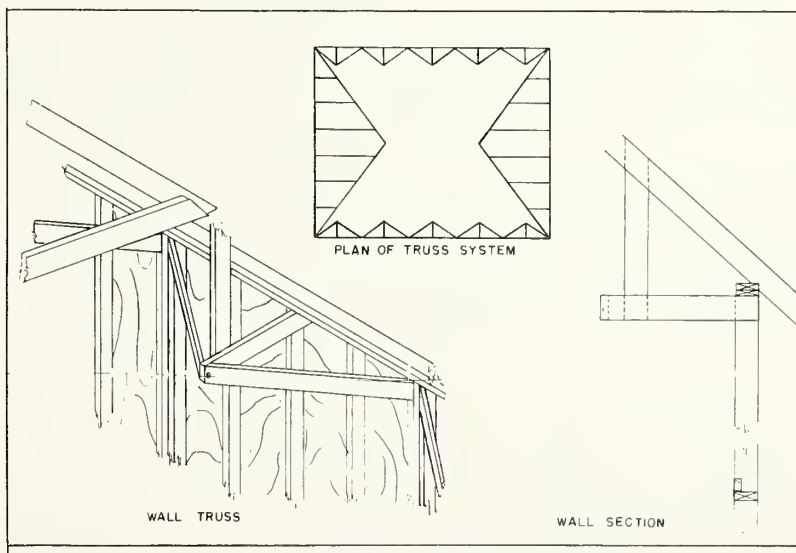
Figure 2.--(Bottom) a. Flat storage originally intended for machinery and small amount of grain. b. Interior arrangement for storing and drying shelled corn.



a



b



c

Figure 3.--Planned reconstruction of old horse barn for drying and storing shelled corn. a. Original framing. b. Wall lowered and roof trussed. c. Side and end wall trussing to resist grain pressure.

MAINTAINING QUALITY OF DRY CORN IN STORAGE
BY FORCED-AIR COOLING AND AERATION

by

Leo E. Holman, Agricultural Engineer
Transportation and Facilities Branch
Agricultural Marketing Service, Marketing Research Division
U. S. Department of Agriculture

After corn is harvested and dried, much of it is stored for varying periods before it is consumed or marketed. Even when dried properly, high quality corn can deteriorate in storage if proper storage conditions are not provided.

One of the problems encountered in grain storage is the movement or migration of moisture within the grain bulk. This often results in an accumulation of moisture in the surface grain during the fall and winter months. This accumulation may become great enough to cause some molding and caking of the surface grain even with grain that is otherwise dry enough for safe storage.

Temperature differences within the grain mass are responsible for the movement and accumulation of moisture in stored corn and other grain. Corn dried with heated air may have temperatures above 80° F. when stored if not cooled to outside temperatures after drying. When fall and winter comes, the exposed top surface and the grain against the walls become chilled, while in the middle of the mass the corn still retains much of its warmth. Cool air between the kernels near the walls moves down, then towards the warmer center. As this air is warmed it picks up moisture from the corn. Being warm it also is light, and so it rises slowly, carrying its load of moisture. Approaching the upper cool surface it becomes cooler and loses its ability to hold so much moisture and the excess is condensed out of the air and absorbed by the cool grain.

Moisture migration and accumulation in stored dry corn is normal in any kind of storage. Grain elevator operators recognize it and have followed the practice of turning the corn during cool weather to reduce, or at least to equalize, the temperature of the stored corn.

Research tests and regular installations have demonstrated that as good or better results can be accomplished by using aeration or cooling systems to move air through the stored corn. By this method, air is moved through the corn rather than the corn being moved through the air as in turning. Extra conveying equipment and empty storage space are not needed and corn breakage and damage are held to a minimum where corn is not turned.

In 1949 fans were installed in a number of Government-owned "flat" storages; that is, storages that have a large floor area and walls only 14 to 20 feet high, and holding from 20,000 to 40,000 bushels. No facilities were available for "turning" the grain economically. The fans moved at least 1/10 cubic feet of air per minute (cfm) per bushel through the stored grain. This amounted to about 1 air change every 5 minutes. A 3/4- to 1½-horsepower electric motor provided sufficient power for operating the fan, which was connected to a central perforated floor duct. Air was drawn down through the grain, into the duct, and exhausted through the fan. The time required to cool the grain to a comparatively uniform and cool temperature ranged from 3 to 10 days depending

on atmospheric conditions, size of aeration unit, and the initial temperature of the grain. A comparison was made between the moisture content of the surface layers in similar cooled and non-cooled storages. In storages cooled during October and November the moisture content of the surface grain increased only from about 12.5 percent up to nearly 15.5 percent. In the non-cooled storages surface moistures increased from about 12.5 percent to above 25.5 percent and considerable damage resulted from the high moisture content.

In 1951, tests were started at Ames, Iowa, using another type of system of cooling and aerating stored grain. With this system a 4- to 8-inch diameter pipe or tube is inserted vertically to a depth of from 8 to 12 feet into the grain at the center of a bin. The lower 5 to 9 feet of the pipe is perforated or provided with openings. A small centrifugal or propeller fan is mounted on the upper end of the pipe. Air is drawn down through the grain, into the perforated pipe, and is exhausted through the fan. The fan delivers from 1/60 to 1/30 cubic feet of air per minute (cfm) per bushel and is driven by a small fractional-horsepower electric motor. With this small volume of air the grain is not expected to cool rapidly.

The fan is started in September or October, or whenever the air temperature is at least 10° F. lower than the grain temperature. The fan can be operated continuously throughout the fall or winter or until the grain is cooled to the desired temperature. There is strong evidence that there is little advantage, and possibly some disadvantage, in cooling grain below 30° F. to 40° F. There is also some evidence that the small fans described above can be operated continuously or intermittently during the entire year; that the "warming-up" of the grain is offset by some drying of the surface grain. More tests are needed to establish definite conclusions.

Limited tests have been made to determine if the use of humidistats and thermostats is feasible for automatic control of fan operation. In the tests fan operation was reduced about 50 percent by the use of such controls. But, grain temperature reduction and surface moisture control was about equal to that with continuous fan operation. The cost of continuous operation of the fans was not high. It was estimated to be from 25 to 35 cents per week.

In some tests fans were replaced by roof ventilators of the suction-type. Such equipment requires no power source and little operational attention. It was estimated that these ventilators delivered about 1/60 cfm per bushel when attached to a 3,250-bushel circular bin 18 feet in diameter and 16-feet high. While not as positive as power-driven fans the wind-ventilators tested did help to equalize grain temperatures and to reduce grain surface moisture accumulations.

Valuable information on mechanical aeration or cooling of stored grain is being obtained from the work being done in connection with the storage of wheat in ships.

In the Hudson River above New York City, and in the James River above Norfolk, Virginia, there are "reserve fleets" of inactive Liberty ships. In 125 or more of these ships the Government has stored more than 28 million bushels of wheat. About 225,000 bushels are stored per ship, with 20,000 to 75,000 bushels in each hold, the holds being up to 56 feet wide and filled about 20 feet deep.

Six motor-driven propeller fans were installed in each ship. Because of the limited available electric power it was necessary to use small fans and motor. Each of the fans moves about 1/30 to 1/40 cfm per bushel through the stored wheat.

Two lines of 8-inch diameter perforated tubes were laid lengthwise on the bottom deck of each hold to provide air ducts for moving air through the wheat. The two lines were placed 8 feet each way from the center of the hold because of the greater width (up to 56 feet) as compared with the 20 feet depth.

Many of the ships were loaded during the summer months. Therefore, the temperature of much of the wheat at both fleets was above 75° F. when stored, with temperatures as high as 85° to 95° F. in many of the ships. Even during the winter months much of the wheat in the central section of the hold cooled slowly unless cooled with the aeration systems. At the same time the outer layers of wheat cooled quickly with cold air above the wheat and cold water around it. With the warm wheat surrounded by cool wheat, convection currents developed that caused moisture migration within the grain bulk. This was illustrated in one ship loaded in August 1953 with wheat having an average moisture content of about 12 percent. Wheat samples taken in January 1954 showed the following moistures:

Surface	- 13.8 percent
16 to 24 inches below surface	- 12.5 percent
40 to 48 inches below surface	- 11.9 percent

The wheat temperature near the surface at that time was 37° F. while that in the center of the bulk was 77° F. This wheat was aerated and cooled thus eliminating the convection currents and stopping the moisture migration.

It is obvious that the small fans delivering only 1/30 to 1/40 cfm per bushel cannot cool the wheat quickly. They have to be operated for a long period during cool or cold weather in order to cool the grain to near the outside air temperature.

The fans are generally operated from 800 to 1,000 hours during the fall and winter months. By April 1 much of the wheat at the Hudson River fleet will have temperatures below 45° F. and wheat at the James River fleet temperatures below 50° F. About 1 kilowatt-hour of electricity per 100 bushels of stored wheat is used in aerating and cooling the wheat each season. Thus, for a full season of aeration, a bushel of wheat requires only as much electricity as burning a 60-watt light for about 10 minutes.

Mechanical aeration also is moving into the commercial grain storage picture very fast. At a recent national convention of grain superintendents predictions were made that within a few years 90 percent of the terminal grain elevators will be equipped for aeration of binned grain.

It is evident that mechanical aeration and cooling will have a place in future programs for both farm and commercial storages. The small amount of air used -- about a quart per minute per bushel -- is not costly to provide. It must be remembered, however, that such small amounts are not sufficient for drying damp grain but are to be used only in maintaining the market quality of dry stored grain.

498

Th
de
fe
in
fe
W
sl
F
p
i
A
A
o
p
c
M
C
b
h
t
f
i
e
L
C
V
C
V
S
S
:
C
C
V
S
:

FARM MANAGEMENT RELATIONSHIPS
Introductory Statement

by

O. J. Scoville, Head Farming Efficiency Section
Production Economics Research Branch
Agricultural Research Service, U. S. Dept. of Agriculture

The purpose of economic research on new farm technology is to study new developments as they come along to see what kind of problems they raise for farmers and to see how they can be used to increase profits, and what the implications are for agriculture as a whole with respect to organization of farms and regional shifts in production.

We are concerned in this instance with the whole process of picking, shelling, drying, storing, and feeding, or otherwise disposing of corn.

Farmers are interested in knowing how changes in this process will affect production costs, the effects on other farming operations, and the changes in organization needed to make the new technique most profitable.

At present there are only a few field-shellers and farm grain dryers. According to a recent estimate supplied by the Economic Research Department of Deere and Company, there are about 2,200 field shellers and 1,500 corn picking attachments for combines. These estimates include machines made or converted by farmers. No estimate of the number of farm dryers is available.

Most of the field shellers and farm dryers are on the larger farms in the Corn Belt. How far is this development likely to spread geographically and by size of farm? Corn is grown on about $3\frac{1}{2}$ million farms, but more than half of the corn acreage is in the Corn Belt. Over 40 percent of the farms that have corn grow less than 11 acres. There are only one-third million farms with 50 acres or more. How many acres of corn are needed for economical ownership of a picker-sheller and dryer? Will custom field-shelling and drying services develop for farmers with small acreages? What are the possibilities of using farm dryers for a number of crops to reduce overhead costs?

We estimate that there are about 700 thousand cornpickers on farms, an increase of 50 percent since 1950. Over half of these are in the Corn Belt, but the most rapid rates of increase in the past 5 years have been in the South, Northeast, and the far West.

Studies show that storage problems have an important bearing on the decision to shell corn in the field. All corn harvested for grain needs to be stored in some manner, but these needs are greatest where corn is sold in commercial channels as in the surplus producing areas, or where storage is difficult as in the South and humid areas.

With respect to the proportion of corn sold off the farm where grown the highest percentages are in the Pacific Coast States followed by the Northern Plains and the Corn Belt. A very low percentage is sold off the farm in the Southeast. Most of the corn stored under CSS price support programs is in the Corn Belt, Northern Plains, and Lake States.

Among the general implications of field shelling and drying of corn, reduction in storage losses should be mentioned. Losses from insects and molds are reduced by drying, and in addition, shelled corn can be stored in tight bins that permit fumigation. Storage losses for corn from molds, heating, and rodents has been estimated to run about 6 percent of production. Losses from insects are estimated at about $2\frac{1}{2}$ percent. In 1952, the estimated loss of corn in storage was 52 million bushels from insects alone. Of this, 42 million bushels were in the South. Not all of this corn could be saved by improved drying and storage, but a substantial part of it could be.^{1/}

In addition to reduced storage losses, the earlier harvest made possible by field shelling and drying permits substantial savings of corn in the field.

^{1/} Estimates derived from Agricultural Research Service, "Losses in Agriculture," ARS 20-1 U. S. Department of Agriculture. Washington. June 1954.

THE FARM MANAGER LOOKS AT CORN HARVESTING AND STORAGE ALTERNATIVES

by

DOUGLAS F. GRAVES Assistant Secretary and Farm Manager
The Northern Trust Company Chicago, Illinois

In 1949 I found myself in the position of managing farms in nearly every state of the Corn Belt. This situation provided many and varied problems in regard to the harvesting, storing, and marketing of grain and particularly corn. At that time the major problem appeared to be one of eliminating the heavy market discount due to excessive moisture and spoiled corn. The excessive moisture was in some instances due to early and unexpected frost and in other instances due to the normal short-growing season in the northern part of the Corn Belt. During the past several years, other problems have developed which have been equally costly to the farmer.

Before discussing the problems and how we have attempted to solve them, I would like to make my position clear and explain how the professional farm manager looks at harvesting, drying equipment and corn storage. The farm manager always has, or should have, as his objective the maximization of the farm's long-term net income. To accomplish this objective, it is necessary that he look at every idea, every project, every expenditure and every result with a rather cold, calculating, and impersonal eye. Every proposed expenditure must be looked at in terms of alternative investment opportunities and the anticipated returns from the various alternatives.

It is the manager's responsibility to determine and to make recommendations as to where a dollar spent will net the greatest return. In some cases it may be more profitable to apply extra fertilizer and sell corn from the field rather than provide storage or drying facilities. Or it may be more profitable to install additional tile drainage or invest in livestock or equipment. With this in mind the Farm Manager must look at grain and harvest storage as only one of many alternatives for investment of additional capital.

For the Farm Manager some of the major problems of harvesting, storing and marketing of corn may be listed as follows:

1. Field losses of shelled and ear corn.
2. High cost of crib construction.
3. Low market price at peak of harvest.
4. High discount for moisture when selling.
5. Preparing of corn for safe storage.
6. The single purpose corn crib.
7. Income loss due to selling corn below 15.5 percent moisture.
8. Anticipation of price behavior during the storage period.

It is the Farm Manager's responsibility to get the job done and done right the first time. However, seven years ago when we were considering the installation of a dryer, we found there was little information available for the layman. We checked with manufacturers, engineers and colleges only to find a complete lack of agreement as to what would or would not work. As a result, we developed our own plan for an installation which was a composite of many ideas which we have since found to be both good and bad.

In an effort to solve the problems listed above, we have installed four methods of handling corn. The various arrangements have been adapted to rectify the following situations:

1. Insufficient and inadequate crib space on the farm.
2. No storage available on the farm.
3. Conventional cribs in excellent condition but inadequate for present needs.
4. Insufficient storage and a limited amount of capital to provide additional storage.

Today we have in addition to the conventional storage the following four types of grain harvest, storage and drying facilities:

1. Heated Air Grain Dryer and Storage

This installation is permanent and serves several farms. The corn is placed in permanent cribs on the individual farms, from which it is shelled and delivered to the dryer site. Since we do not advocate expensive pole cribs, and because the high moisture corn was always a problem on these farms, we sought an inexpensive solution to the problem of soft corn and inadequate storage. Conventional ear corn storage would have cost approximately \$1 per bushel. We were able to provide shelled corn storage, a dryer and moving equipment for approximately this cost. The first year of operation 40 cents a bushel was added to the value of the corn dried over the value of the corn delivered and sold directly from the cribs. This increase was due to improving the grade of high moisture corn and the seasonal rise in price. Since the original investment, we have added additional storage for less than 50 cents per bushel for buildings, foundations and grain-moving equipment.

We are now installing a smaller unit on a 240 acre farm. This installation will consist of a dryer and several bins. It is planned that we provide 10,000 bushels of corn or bean storage and all of the equipment for 60-70 cents per bushel, which is considerably cheaper than a conventional crib.

2. Ear Corn Storage and Forced Cold Air

Since its installation four years ago, we have not harvested corn above 26% moisture; therefore, we do not have any experience with this unit with high moisture corn. Consideration is now being given to converting this to shelled corn storage. The objection to the ear corn is the high storage cost per bushel.

3. Picker-Sheller-Dryer and Ear Corn Storage

This heated air unit was installed when the ear corn facilities were in excellent condition, but inadequate. A wood crib was kept for ear corn to be used in corn-and-cob meal for cattle feed and to have a place to put corn when harvesting got ahead of drying. The ventilated concrete stave crib was converted to shelled corn storage by lining the inside of the crib with hardware cloth, and making a few structural changes. During the drying operation, when the picker gets ahead of the dryer, the sheller is removed and a few loads of ear corn are picked for the conventional crib. In 1954, 5,000 bushels of corn on this farm stood under water for ten days. When the water receded, the corn cobs were molded and the corn was worth approximately 50 cents per bushel. The variable cost of drying the corn for fuel and power was about 3 cents per bushel. The corn sold as No. 2 corn for \$1.50 per bushel.

4. Picker-Sheller

Because of the lack of capital we have several situations where the corn was harvested in 1955 with a picker-sheller and sold from the field. This was not successful because harvest was delayed until the corn was too dry and as a result a large amount was lost, due to the corn which was down and shelled.

Each of the above methods were developed to meet one of the problems outlined in the opening paragraphs. Several years ago I made the statement that it was not practical to build a conventional corn crib north of U. S. Highway 30. Today this would be phrased as follows: "I would question the advisability of constructing a conventional crib anywhere." We could well find the conventional wooden crib as outmoded in 15 years as the horse barn is today. The barns have now been converted into machine sheds, hog-houses, and even grain storage, but what could be done with a crib.

A Farm Manager's objections to the conventional crib are: (1) It is a single purpose building which is not suited to efficient drying of corn. (2) The costs of construction and maintenance are excessive. The advantages of a bulk storage building are: (1) It is a multiple use building. (2) This type of structure may be used 12 months of the year; when the corn has been removed, the building may be used for other grain, feed, fertilizer, machinery and even livestock. The conventional wooden crib is a 3-to-9 months building, rather than a 12-month building.

The question most frequently asked is "How many bushels of corn must you handle before you can afford a dryer arrangement?" This question cannot be answered by just giving a figure like 4,000 or 10,000 bushels, because it will depend upon many factors. A Farm Manager must consider all factors which have a bearing on the decision as to the type of storage to provide. Some of the factors which must be considered are:

1. The present storage facilities
 - (a) Amount available and amount additional storage needed.
 - (b) Repairs needed now and during the next ten years.
 - (c) Cost to repair cribs and additional space.
2. Anticipated profit from storing corn due to increased prices and upgrading.
3. What is the farm program in regard to livestock, Government crop programs and grain sale?
4. The probability of loss due to early frost, excessive field losses due to insects, shelling, weather and crib losses.
5. The contribution of the landlord and tennant towards the purchase of drying equipment and the terms of the lease in regards to the drying of grain.
6. The cost of drying various amounts of corn at different moisture content at various price levels.
7. The imperfection in the marketing system.
8. The alternative investment opportunities for the owner.
9. What equipment is available?

The above factors will be considered independently, however in practice several of them would be considered simultaneously. For the sake of this discussion, it is assumed that the present storage facilities are inadequate to store the entire corn crop.

The following represents some of the thinking a farm manager does in arriving at an answer to the question, "Should I recommend that the owner install bulk storage and artificial drying equipment?"

PRESENT STORAGE FACILITIES

The cost of repairing the present crib and the cost of providing new storage must be determined. This figure should then be compared with the cost of providing drying facilities and storage. It should be remembered that when repairing and adding to the present facilities you still end up with a conventional type crib and you are still subject to field and crib losses and moisture discounts. The anticipated yearly repairs to wood cribs should also be figured on the basis of the corn remaining in the crib until September. The damage to the crib may become excessive when corn remains in the crib for ten or eleven months.

ANTICIPATED PROFIT

The anticipated profit from storage due to holding the corn will be the same for either type of storage. However, the anticipated profit from upgrading of corn will vary considerably. The amount of this variation will depend upon when the corn is sold and the moisture content of the corn when sold from the crib. In addition, the weather condition during storage period will effect the cribbed corn. The normal amount of discount to be expected due to excessive moisture may be determined by past history of the farm. To arrive at a figure per bushel you must know what the average moisture content of the corn has been when the corn has been sold. Is the corn sold during the winter, before taxes are assessed in the spring or is it held until early or late summer. How often has the corn gone out of condition and had to be sold before the total profit could be realized from holding.

The increase in prices is not all profit as certain costs associated with storage must be deducted. These costs will vary depending upon whether or not storage is available and the cost of repair or new storage. The interest charge against the corn will also vary. If the corn is sealed under the Government's program and the individual has this money for his use and if he uses the money the interest would be considered additional income. If the corn is placed in the crib and not sold the charge for interest would vary, depending upon what use would be made of the proceeds from the corn were it sold. If it were customary that the proceeds from the sale of the corn not be used for several months then there would be no charge against holding the corn. All of these factors must be considered and the increased income per bushel and the cost per bushel will vary considerably depending upon the particular situation*. In addition to these the individual's personal income

* SHUTE, JAMES A., "Corn and Soybeans - Store or Sell"
Economic and Marketing Information for Indiana Farmers,
Purdue University, August 25, 1953

tax position and rate of write off may be an influencing factor.

WHAT IS THE FARM PROGRAM

If the farm program includes cattle feeding or dairy, it will be advisable to keep some storage for ear corn. There is also less danger of loss because of soft corn and field losses if livestock clean the fields. However, it is impossible for the stock to recover all the down corn and soft corn does not have the same feeding value of #2 corn.

If the farm is cooperating in the Government crop control program it is necessary to have adequate storage. If this corn is not eligible for sealing because of high moisture, the losses could be equal to the cost of providing artificial drying facilities. Also under certain circumstances it may be advisable to seal the corn produced and purchase corn at harvest time for feed. This type of operation can be very profitable when the corn is purchased at the low market price with the high moisture discounts.

If the corn is sealed the cost of insurance is shifted from the owner to the Government.

FROST AND FIELD LOSSES

The probability of damage to the corn due to early frost and field losses can readily be determined. If records have been kept on the farm they will indicate the years there was an early frost and the discount on the corn because of high moisture. The field losses can also be determined if records have been kept, indicating when there was wind damage, heavy insect damage, exceedingly wet or dry corn at harvest time and loss during storage due to mold, rodents, insects, etc. All of these causes may contribute to as much as 10 or 20% loss of a crop in any one year. It may also be possible to increase yields by planting later maturing corn which can be artificially dried. When the average loss in actual yield or potential yields have been determined, these figures should be converted into dollars for the entire crop. This figure will then be useful in determining the amount of additional income possible due to the artificial drying of corn.

CONTRIBUTION OF LANDLORD AND TENANT

There are other important factors which must be considered, such as the sharing of the cost of drying equipment between the landlord and tenant. This includes fans, motors, heating units, elevators, etc. The sharing of these expenses will vary from farm to farm and from tenant to tenant. Since much of this equipment is not considered real estate, the sharing of the cost will be open to

negotiation and bargaining between the landlord and tenant. It is assumed that the tenant will furnish all of the picking, combining, shelling and transportation equipment.

With the introduction of drying equipment we are going to be faced with a whole new group of problems. Many of these problems will not present themselves until you have a situation of a dissatisfied tenant who has canceled or has had his lease canceled. When this situation does develop, how is the manager or owner going to protect himself against the improper drying by air or heat, overheating of equipment and corn, or what if the tenant should refuse to dry the owners corn? All of these situations must be anticipated and provision made to protect the owner's investment and grain before the problems develop, not after it is too late. For this reason, it may be necessary to have both landlord and tenant have an investment in the same equipment. It is also necessary that the present leases be changed to meet these new problems.

PRODUCTION FUNCTIONS (input-output relationships)

This is one of the major problems and may be the key to the entire discussion. The big question for everyone is, "When will it pay to dry corn artificially?" If the men in research would prepare a series of production functions for the cost of artificially drying corn, we would know the number of bushels needed to be handled before a change should or could be made. The production functions should take into consideration the price of corn, discount, schedules, shrinkage and cost of drying under various methods and with various amounts of moisture in the corn. It is necessary to include all fixed and variable costs on this analysis.

Until this information is available it will be necessary to work with the bits of information we now have. This is particularly true with heated air drying. The cost of cold air drying will also vary depending upon the weather conditions.

IMPERFECTIONS IN THE MARKETING SYSTEM

We have not found it economically sound to dry corn when it is shelled at 21% moisture. This situation is the result of imperfection in our marketing system which does not pay a bonus for corn below 15 1/2% moisture. When corn is sold at 19% moisture it nets an amount equal to that of corn selling at 13% moisture because at 13% you are selling at about a 5% discount due to shrinkage. The figure of 21% moisture was used as a breaking

point because the increase in price received for 19% rather than 21% moisture pays the variable cost of drying.

ALTERNATIVE INVESTMENT OPPORTUNITIES

The net income due to artificially drying of corn may vary from nothing to almost any practical figure depending upon the above factors. When the average net return has been determined for each individual the next step is to determine if this investment is as profitable as any other investment the owner could make. These investment opportunities may be on the farm or they may be in another business or investments in stocks and bonds.

EQUIPMENT

The installation of drying equipment involves more than just buildings, fans, heat units and drying bins. The installation of a complete corn drying set-up includes much planning in regard to the type of harvesting equipment, storage equipment and grain moving equipment. All of this equipment must be coordinated and installed by someone that knows the capacities and limitations of all of the equipment. It is the farm manager's problem to find the equipment that is easy and safe to operate, equipment with sufficient safety features to prevent damaged corn in harvesting, drying, moving and storage. The equipment which will most efficiently and economically harvest - dry, move and store the grain with the least damage to the grain will be the equipment purchased by the professional farm manager.

FARM MANAGEMENT AND ECONOMIC PROBLEMS ACCOMPANYING FIELD SHELLING AND ARTIFICIAL DRYING OF CORN

by

Roy N. Van Arsdall, Agricultural Economist,
Production Economics Research Branch,
Agricultural Research Service, U. S. Dept. of Agriculture,
University of Illinois, Urbana, Illinois

Field shellers and artificial driers are not new inventions. A corn combine was introduced into western Nebraska in the early thirties and a picker sheller came on the market in 1937. Crop driers have been available for many years. The application of this equipment to practical farm operations is a new development. Since 1950, such things as shortage of grain storage, high cost of conventional ear corn storage structures, development of rural electrification and the accompanying materials handling devices, and the manufacture of batch-type driers on a commercial scale have combined to bring field shelling and artificial drying into use on farms.

The United States Department of Agriculture data show nearly 100,000 mechanical cornpickers in use on Illinois farms in 1954. By the end of the 1954 harvest season, approximately 275 field shellers and 175 heated air driers for handling shelled corn were in use in the state. Ninety percent of the driers were installed since 1950, half of them in 1953 and 1954. Field shellers in 1954 amounted to less than one-half of 1 percent of all mechanical pickers, and their number is probably still below 1 percent. Thus, public and private research workers are in the unique position of being able to observe and guide this new development in corn harvesting.

Studies in Illinois

Preliminary work. In 1953, the University of Illinois made a preliminary study of the costs of harvesting, drying, and storing shelled corn. ^{1/} Cost data were compiled from secondary sources, primarily engineering research studies. This study provided some basic cost information. The laboratory experiments on which these data were based, however, were not designed to explore the problems of operating new equipment in the field and integrating a new technique into Corn Belt farming. One of the chief reasons for making a field study of harvesting on Illinois farms was to obtain a first-hand accounting of the problems of installing and operating the equipment and carrying the corn through to disposition. Some practices that appear simple in the textbook prove to be troublesome when applied on the farm.

Field study. Prior to the 1954 harvest season, 77 Illinois farmers who used field shellers and artificial driers were interviewed concerning their farm organization and corn-harvesting operations. Forty-five of these farmers kept detailed operation records throughout the 1954 corn harvest season.

^{1/} Swanson, E. R., Costs of Harvesting and Storing Corn. University of Illinois, Department of Agricultural Economics. AE2989.

Man-machine analysis, field loss checks and general observations were made on 23 of these farms during harvest. Additional information was collected at the close of the season and after disposition of the 1954 crop had been completed in 1955.

Farm characteristics. Most of the farms that used shellers and driers in 1954 were in the northern half of the state. Approximately half were located in the east-central cash grain area. The average size of farm studied ranged from 417 acres in the east-central area to 613 acres in the north-eastern section, but a few 160-acre farms were included. These farms were nearly three times the size of the average farm in each area. A survey study of Indiana farms using grain driers for shelled corn also revealed that driers are on the larger farms.^{2/} Nearly half of the tillable land on the Illinois farms studied was planted to corn with oats, soybeans, and wheat amounting to 16, 14, and 4 percent respectively.

Equal numbers of the farms were classified as grain and livestock farms, although most of them had relatively large livestock enterprises. Only 12 farms had no livestock. About two-thirds of the 1954 crop of dried corn was eventually sold. This was representative of all farms in the east-central cash grain area, but considerably higher than average sales from the livestock areas of western and northern Illinois. One-third of the farms studied harvested some ear corn, most of which was fed.

Twenty-eight of the 77 farms were operated by tenants.

Reasons for shelling and drying. Economists and engineers can list many reasons why farmers should or should not adopt new equipment and practices. These reasons usually have merit but they do not always conform to those of the farm operators. Each of the Illinois farmers contacted was asked why he made the change to field shelling and artificial drying. Most farmers gave more than one reason. Eighty percent named a storage problem such as shortage of space, a need for crib replacement, and lower cost of storing shelled corn as one of the compelling reasons for making the shift. An approximate third mentioned advantages relating to less work and easier work. A fourth included reductions in field losses as an important factor. Protection against storage losses, earlier marketing, fall plowing, wheat following corn, corn of better quality and other factors were in the minority. They were mentioned by not more than 1 in 10 farmers.

Picking. Field shelling operations were generally successful as the machine operation was similar to conventional ear corn pickers with which all operators were thoroughly familiar. Picking speed averaged only 2.5 miles per hour which is slower than many farmers run conventional pickers. Thus, it is probable that an above-average job of picking was accomplished. A few instances of excessive kernel damage and a high proportion of foreign material were noted when harvesting was begun with corn containing more than 30-percent moisture. Total field losses averaged 8 percent of the gross yield with three-fourths of the loss occurring from machine operation. The

^{2/} Snodgrass, M. M., Hardin, L. S. and Foster, G. H., An Economic Analysis of Drying Wheat and Corn on Indiana Farms. Station Bulletin 630, Purdue University, Agricultural Experiment Station, 1955.

machine loss was about two-thirds shelled corn and one-third ear corn.

Average rate of picking was a little over 7 acres a day, counting only those days when some corn was picked. Counting all days in the harvest season, the average rate of picking was only 4.1 acres per day.

Drying. Most of the serious difficulties occurred in the drying operations. The drier was frequently a bottleneck in the harvesting operation because (1) its capacity was considerably below that of the field sheller, or (2) facilities for loading and unloading the drier were inadequate. These difficulties were accentuated when the moisture content of the corn was high. Part of the difficulty was a result of the nature of farm drying equipment, and the variability of grain moisture and weather; part of it resulted because farmers failed to match their equipment with respect to capacities.

Control over the final moisture content was a second major problem. Generally the goal was to dry to 15.5 percent for market corn and 13 percent for corn to be stored on the farm. Final moisture contents actually ranged from 9 to 17 percent. The exact goal was seldom attained. Farmers who dried corn below the basic bid level (15.5 percent) added to their drying costs and dried away more water than was necessary. Underdried corn (more than 13-percent moisture content) usually caused trouble in storage. Reasons for difficulty in hitting the mark included improper sampling procedures, inadequate moisture-testing techniques, ineffective moisture testers, and a lack of knowledge as to the full significance of moisture content.

Farm driers should be designed with more adequate built-in controls than they now have. A farmer should be able to set the controls for the desired ending moisture and be relieved of the burden of continual testing. The general farm descriptions previously given, plus personal contacts with individual farm operators, convinced us that we were dealing with some of the most competent farm managers in the state. The same equipment in the hands of less capable managers probably would have resulted in more frequent and more serious errors in the drying process.

Storage. Thirty-seven of 57 farmers who answered a questionnaire concerning their 1954 storage experiences encountered heating, crusting, insect damage, or a combination of these problems. In most instances, their detailed records showed that one or more batches of corn had been stored at an excessively high moisture content. Accumulations of trash and fine particles of grain under the unloading spouts were the beginning of trouble areas in many bins. Only a few operators, however, attempted to clean the corn as it was moved through the drier and into storage. Corn harvested in the 80- to 90-degree weather that often occurs in late September and October is particularly susceptible to damage that results from moisture migration. No doubt this caused much of the difficulty with the 1954 crop. Grain-conditioning equipment, although relatively inexpensive, was almost nonexistent on these farms. Probably farmers will need to make some provision for cleaning and conditioning corn for successful drying operations in the future.

Difficulties were noted in converting cribs for ear corn to storage of shelled corn. Inexpensive methods for making different types of cribs tight for shelled corn, specifications for reinforcing different types of cribs, and general recommendations for determining when it would be more economical to buy new structures rather than to convert existing structures, were among the more apparent needs. A problem on which many farmers will need help in the future appears to be that of utilizing existing structures most effectively for shelled corn.

Costs. No general statement can be made as to the profitability of shelling and drying without considering the individual instances. Many different advantages or disadvantages may apply and thus alter the costs and benefits that depend on the particular situation. This will be true for years to come.

It is relatively simple to figure costs for the so-called "clean slate" situations. They provide some useful comparisons. Even here, however, we must apply estimates of fixed costs (the major part of total costs) which may or may not agree with actual wear-out periods, obsolescence, or rate of return that farmers use as a basis for deciding whether or not to make a new investment. For clarity and brevity two "clean slate" situations are presented here: (1) Selling high-moisture corn at harvest time compared with drying corn for sale, and (2) harvesting ear corn to be stored on the farm compared with field shelling and artificial drying of corn to be stored on the farm.

Selling corn at harvest. Major factors involved in considering whether it will pay to buy a drier to dry corn for direct sale at harvest include: (1) Initial cost of the drying equipment; (2) operating costs; (3) average moisture before drying; (4) discount for high-moisture corn; and (5) quantity of corn to be dried. Table 1 presents a situation typical of recent market relationships and costs of drying.

Care must be exercised in manipulating figures that involve pounds, bushels, percentages, percentage points, dry matter, and discount rates all of which are involved in corn-moisture problems. These relationships are complicated at best. An error sometimes made lies in assuming that the full difference between the discounted price and the basic bid for number 2 corn is a loss to the farmer. This is not true. Some extra water in high-moisture corn is included in the sale weight. For example, the discount for 22-percent corn is 21.5 cents a bushel. Drying this same bushel of corn to 15.5 percent moisture results in the loss of 4.3 pounds of water, or 11.5 cents a bushel when number 2 corn sells at \$1.50 a bushel. Thus the loss from selling 22-percent corn as compared with drying it to 15.5 percent before sale is not 21.5 cents. It is the discount minus value of shrinkage (21.5 - 11.5), or 10.0 cents per bushel.

Break-even points are shown also in Table 1 for drying from various levels of average moisture content to 15.5 percent. These break-even points serve as guides, but they require careful interpretation to avoid misleading conclusions. Obviously, a farmer would have difficulty in making a drier pay if the average initial moisture content were below 20 percent. At high

moisture levels, however, it appears that no more than 20 or 30 acres of corn are needed to make a drier profitable. This is true if corn is sold at an average of 28 to 30 percent moisture, but it does not represent a practical situation. Standing corn with a relatively high moisture content will lose an average of about one-half point of moisture per day. Thirty-percent corn is about the upper limit for harvesting without excessive damage to the kernels. In most corn-producing areas, there is seldom any necessity for harvesting small acreages at high moisture. The farmer can wait until the moisture content decreases naturally and still complete harvest ahead of hazardous weather and before significant field losses occur. A farmer with a large crop may begin harvest with moisture near 30 percent but it will probably be 20 percent or below by the end of harvest. Average moisture of corn coming from the field was 22 percent on the 77 farms in the Illinois study. Thus the basis for decision-making lies in the relationships around the average moistures of 20 to 23 percent for most farms, with the extremes seldom having any practical significance. If a farmer already owns a dryer, fixed costs do not affect his decision, and drying would be profitable down to an initial average moisture content of 17 percent, assuming the final moisture level can be accurately controlled. However, unless corn can be dried exactly to 15.5 percent, drying corn that is harvested at 20 percent moisture or less may not pay if the corn is to be sold soon. The loss in weight from over drying can easily offset the elimination of the discount for excess moisture.

Two additional factors limit this type of break-even analysis. First the discount schedule is relatively less flexible than the price of corn. With a rigid discount schedule, drying is more favorable with low than with high prices for corn because the discount is a stated amount while shrinkage from drying is a percentage. Second, both the discount schedule and the price of corn are subject to change, thus complicating the analysis in Table 1 that corn can be dried to exactly 15.5 percent moisture. Controls that now exist will not permit such accuracy.

Storing corn on the farm. One-half of the Illinois corn crop is fed on the farms where it is produced. A cost and return analysis which assumes that corn is to be stored on the farm either for feed or future sale, is thus applicable to a greater proportion of Illinois (and Corn Belt) farms than is the previous direct-sale analysis.

The data in Table 2 indicate a possible situation for farms having 80 and 160 acres of corn yielding an average of 75 bushels an acre. All facilities are assumed to be new. Differences between the two methods are not large based on direct costs and benefits. Final appraisal of the two alternatives must be based on each farm situation and individual evaluation of many factors, such as livestock needs, advantages and disadvantages of earlier harvest, value of easier work, and the like.

Storing high-moisture corn. Storing high-moisture corn in gastight bins is an alternative to drying if the grain is to be fed on the farm. Corn can be harvested as soon as the moisture content is low enough to permit effective field shelling; moisture may be higher than 30 percent as kernel damage is

Table 1.--Break-even analysis for selling high-moisture corn at harvest versus drying corn to 15.5 percent before marketing.

Moisture (percent)	Discount (per bushel)	Loss from shrinkage (corn at 1/ \$1.50) 2/	Direct drying costs 3/	Gain from drying 4/	Bushels to break even 5/ Wet : No. 2 corn : corn	
	Cents	Cents	Cents	Cents	Bushels	Bushels
15.5	0	0	0	0	0	0
16	1.5	1.0	1.22	- .72	6/	6/
17	4.5	2.7	1.47	.33	6/	6/
18	7.5	4.4	1.72	1.38	6/	6/
19	10.5	6.2	1.96	2.34	6/	6/
20	13.5	8.0	2.21	3.29	13,000	12,300
21	17.5	9.8	2.45	5.25	8,100	7,600
22	21.5	11.5	2.70	7.30	5,900	5,400
23	25.5	13.3	2.94	9.26	4,600	4,200
24	30.5	15.1	3.19	12.21	3,500	3,100
26	40.5	18.6	3.69	18.21	2,400	2,100
30	60.5	25.7	4.67	30.13	1,400	1,200

1/ Based on the discount schedule commonly in use in Illinois in 1955; 15.6 to 20.0 percent moisture, $1\frac{1}{2}$ cents for each $\frac{1}{2}$ percent moisture; 20.1 to 23.0, 2 cents for each $\frac{1}{2}$ percent moisture; above 23.0 percent, $2\frac{1}{2}$ cents for each $\frac{1}{2}$ percent moisture.

2/ Shrinkage is calculated by the following equation:

$$1 - \left(\frac{100 - \text{initial moisture}}{100 - \text{final moisture}} \right) \quad \text{basic bid for No. 2 corn}$$

3/ Cents calculated on the basis of \$3.71 per 1,000 pounds of water removed plus \$.40 labor charge per 100 bushels dried plus 0.5 percent invisible loss.

4/ Gain from drying at stated moisture levels equals the market discount minus the sum of shrinkage and direct drying costs. The gain also equals the fixed cost per bushel at break-even volumes.

5/ Total fixed costs were \$428: a medium capacity batch-type drier with a maximum life of 13 years, or 154,000 bushels, and common carrying charges. Bushels rounded to nearest 100.

6/ Drying is impracticable at any level below 20-percent average moisture as the gain from drying will not cover fixed costs regardless of volume.

Table 2.--Analysis of cost of harvesting and storing ear and shelled corn under stated conditions

Item	80 acres		160 acres	
	of corn		of corn	
	Ear	Shelled	Ear	Shelled
	Dollars	Dollars	Dollars	Dollars
Investment in equipment:				
Harvester 2/.....	1,520	1,920	1,520	1,920
Drier 3/.....	---	3,650	---	3,650
Storage 4/.....	7,260	2,114	11,616	4,229
Total	8,780	7,684	13,136	9,799
Quantity of corn:	Bushels	Bushels	Bushels	Bushels
Harvested 5/.....	5,280	5,520	10,560	11,040
Stored 6/.....	5,280	5,492	10,560	10,985
After Storage 7/.....	5,122	5,437	10,243	10,875
Sold 8/.....	4,974	5,280	9,948	10,562
Annual costs, total:	Dollars	Dollars	Dollars	Dollars
Harvesting 9/.....	398	470	565	657
Drying 10/.....	---	581	---	733
Storage 11/.....	508	148	813	296
Shelling 12/.....	124	---	249	---
Total	1,030	1,199	1,627	1,686
Annual costs, per bushel sold:				
Harvesting .....	.080	.089	.057	.062
Drying	---	.110	---	.069
Storage .....	.102	.028	.082	.028
Shelling .....	.025	---	.025	---
Total .....	.207	.227	.164	.159
Sale value at \$1.50 per bushel ..	7,461	7,920	14,922	15,843
Sale value less cost	6,431	6,721	13,295	14,157
Gain from shelling and drying ...		290		862

- 1/ Gross yield 75 bushels per acre. All bushel data except bushels sold are in terms of corn with 15.5 percent moisture.
- 2/ Approximate cost of a 2-row mounted picker and pull-type field sheller. Hauling and unloading equipment assumed to cost the same and are omitted.
- 3/ Medium capacity batch-type drying unit, including fuel tank, moisture tester, and drier installation.
- 4/ Structures of equivalent durability costing \$0.35 per bushel for shelled corn space and \$1.00 to \$1.25 per bushel for ear corn storage, depending on size of crib. Total cost calculated for 10-percent excess capacity.
- 5/ Assumes field losses of 12 percent of gross yield for ear corn and 8 percent for shelled corn.
- 6/ Assumes 0.5 percent loss, other than moisture, during artificial drying.
- 7/ Assumes 3-percent loss in storage for ear corn; 1 percent for shelled corn.
- 8/ Assumes both ear and shelled corn sold at 13 percent moisture.
- 9/ Based on total costs per 100 bushels harvested of \$7.53 and \$5.35 for the smaller and larger quantities of ear corn; \$8.52 and \$5.95 per 100 bushels for shelled corn.
- 10/ \$428 annual fixed cost plus operating costs of \$3.71 per 1,000 pounds of water removed and a labor charge of \$0.40 per 100 bushels.
- 11/ Annual costs calculated at 7 percent of initial investment.
- 12/ Shelling charge 2.5 cents per bushel.

unimportant. The same field shelling and hauling equipment is used as in a drying operation. A 2-man crew can harvest at the maximum rate of the field sheller, or from 1,200 to 1,400 bushels a day. This harvesting rate cannot be achieved with an average capacity drier, particularly with corn at the higher moisture levels.

The initial cost of a unit for handling a given amount of high moisture corn is higher than for a drier and storage units for handling a comparable amount of dried corn. Based on annual costs, however, the high-moisture unit is in a more favorable position because of the elimination of drying costs and a lower proportion of the investment is subject to a high rate of depreciation. Offsetting this advantage is the loss of the opportunity to market the corn and the necessity for feeding at rather frequent intervals to prevent spoilage of corn in the feeders. Possible differences in feeding value may be a factor. As with all of these methods of handling corn, the decision hinges primarily on the individual farm situation.

Other Areas of Economic Significance

Many factors of probable economic importance are arising along with these new developments in harvesting corn. Limited information is available concerning some of them; we have been able to do no more than express opinions as to possible future developments in other areas.

Quality of corn. Methods of harvesting, drying, and storing corn may have an effect on the feeding and milling qualities of corn. Some tests of the feeding value of both high-moisture corn and artificially dried corn have been made, but the answers are by no means positive.

Artificially dried corn for feed. Two years ago the animal scientists at the University of Illinois fed two lots of heavy, choice feeder calves for 126 days on rations, including in one instance shelled corn that had been artificially dried at 180 degrees F. from 30 to 16 percent moisture and in the other instance, corn that was field-dried to 16 percent before harvest. Under conditions of their tests, there was no significant difference in rate or cost of gain. ^{3/} This is the result of only one comparison.

High-moisture corn for feed. The feeding value of high-moisture shelled corn stored in gastight bins was first tested at Purdue from 1949 through 1952. ^{4/} Hogs fed corn containing 27 percent moisture that had been stored in sealed bins for two seasons remained healthy and made normal gains. The cost per 100 pounds gain between the lots receiving wet and dry corn was about the same. Differences in consumption of protein supplement, however, indicated a need for further study. Another feeding study that compares high-moisture ground ear corn stored in gastight bins (32.2 percent moisture) with regular ground ear corn (17.7 percent moisture) when fed to 2-year-old

^{3/} Cattle Feeders' Day Report. University of Illinois. November 4, 1955.

^{4/} Foster, G. H. et al. Effects on Corn of Storage in Airtight Bins. Agricultural and Food Chemistry, Vol. 3, No. 8, August 1955.

steers both with and without antibiotics has just been completed at Purdue.^{5/} Results showed that the cattle fed on the high-moisture ground ear corn (converted to 17.7 percent equivalent) required 12 to 15 percent less corn to produce a pound of gain than the cattle fed regular ground ear corn. Also, there was a 3-cent reduction in the cost of feed per pound of gain in favor of the high-moisture corn. Rates of gain were about the same, carcass grades were similar, and the cattle with and without antibiotics reacted similarly to the different forms of corn.

Obviously, these fragmentary comparisons do not give the final answers. These preliminary data plus the many questions received from Illinois live-stock feeders concerning the feeding value, palatability, and digestibility of corn in different forms and with different moisture contents show a definite need for a complete evaluation of all phases of feeding high-moisture corn as compared with feeding naturally or artificially (heated air) dried corn.

Effect of drying on milling quality. Proper drying is important if the grain is to be used by the wet milling industry. It is generally recommended that drying temperature be kept below 130 degrees F. to prevent damage to the milling qualities. Most farmers use higher temperatures in order to maintain a faster rate of drying. Temperatures of 165 to 180 were most common on farms in the Illinois study. With reference to this problem, Dr. R. E. Greenfield, vice president of the Staley Corporation of Decatur, Illinois, told a 1955 Illinois Farm and Home Week audience that the corn-refining industry had generally avoided buying corn known to be artificially dried as no adequate premilling tests were then available to determine whether the milling qualities of the corn had been damaged in the drying process. He pointed out that the corn-refining industry consumed from 20 to 30 percent of all corn sold off farms and nearly 50 percent of all corn used for non-feed uses. Dr. Greenfield further stated that growing use of picker-sheller-drier combinations would create problems for the milling industry in purchasing corn that might well affect the entire cash corn market unless development and general acceptance of proper drying controls could be worked out.

Custom drying. Custom drying on a large scale is not a general practice in the Corn Belt among farmers or with commercial concerns. Farmers who have done some custom drying generally handled only small quantities, usually as a favor for a neighbor. Rates charged on farms in the Illinois study varied from 5 to 16 cents a bushel with 10 cents the most common rate. A few operators charged on the basis of the water removed. Should custom drying increase in the future, there will be a need for more equitable and uniform rates.

The possibility of commercial driers competing with farm driers will probably increase as the proportion of field shelling increases, so that a sufficient volume of business can be obtained. In his study of grain

^{5/} Beeson, W. M. et al. High-Moisture Ground Ear Corn vs. Regular Ground Ear Corn With and Without Antibiotics for Fattening Steers. Purdue University, Department of Animal Science Mimeo. A. H. 169, April 1956.

drying, R. C. Whitney estimated that a commercial drier could probably be operated profitably in Nebraska with a minimum of 50,000 bushels of grain annually. ^{6/} If this were true in Illinois, many areas of the state could support a commercial drier with no more than 5 percent of the corn production within a 10-mile radius of the drier. Many technical problems would be likely to arise in handling large volumes of high-moisture corn over a relatively short harvest, but development of such facilities is likely enough to be worth considering by both farmers and manufacturers.

Landlord-tenant agreements. Tenants operate as much as 70 percent of the land in some areas of the Corn Belt. Traditionally, the landlord has furnished the storage structures while the tenant has harvested the corn and placed it in storage. The use of field shellers, driers, and storage for shelled corn has shifted much of the burden of costs from storage to equipment, thus making necessary a reappraisal of the cost-sharing arrangements between tenants and landlords. On the 24 tenant-operated farms in the Illinois study, 14 different cost-sharing agreements were recorded. The tenant usually owned the harvesting equipment and the landlord owned the drier and storage structures, while the costs of drying were shared equally. The wide differences among tenant farms, however, indicates a need for further examination of this problem.

Scale of operation. Some discussion has already been devoted to the relationships between costs and size of business. Obviously, we have a problem of retaining effective equipment while providing economical facilities for the small producer. This same problem exists with the livestock farmers who may have relatively large acreages of corn but who wish to retain some ear corn in their feeding programs. Multipurpose machines that will harvest different kinds of grains may be a partial answer to reducing high overhead costs. A relatively low-cost unit capable of harvesting either shelled or ear corn may help farmers who continue to demand ear corn for feed. The use of driers for other than corn drying can help to cut the costs of owning a drier. Around a third of the Illinois farmers contacted used their driers for small grains, hay, or as heating and cooling units in livestock operations, in addition to drying corn. In-storage drying with unheated air may be a practical and economical approach for the small producer. These and other possible solutions will need to be examined in the future. Certainly, one size of equipment is not best suited to all sizes of enterprises.

Crop rotation. The effects of field shelling and drying on crop rotations of Corn Belt farms can be examined at present only in terms of possibilities. Most farmers who have made the shift to shelled corn did so for reasons such as storage problems, easier work, lower field losses, and the like. Fall plowing, seeding wheat after corn and other factors relating to rotation changes were seldom primary motives for making the change.

Wheat is not an alternative under existing legislation. Farmers who have not previously grown wheat usually will not break a rotation for the 15 acres allowed without an allotment, even though earlier harvest of corn

^{6/} Whitney, Ramey C., Artificial Grain Drying in Nebraska. Business Research Bulletin No. 55, University of Nebraska, 1952.

would permit such a change. Other wheat growers do not have the allotment for an increase. Also, preparation of land and seeding of wheat would interrupt the corn harvest on most farms. The opportunity for growing wheat remains, if it should become practical in the future.

Varieties of corn. Agronomists report that the yield of corn is directly associated with the time required for maturity. One authority estimated that late maturing hybrids might yield as much as 10 percent more than varieties commonly classified as medium maturing varieties. R. W. Jugenheimer, Professor of Plant Breeding at the University of Illinois, indicated that corn breeders were interested in the possibilities of earlier harvest and later maturing varieties of corn. This factor could have a significant effect on net farm income.

Feeding practices. Changes in feeding practice from ear to shelled corn will probably meet a high degree of resistance. A large segment of the cattle feeders in Illinois firmly believe in feeding ground ear corn. Also, some authorities place a relatively high value on the cob as a part of the ration. This feeling was indicated by a recent request from a group of livestock feeders for assistance in developing a low-cost crib for ear corn that would retain the labor-saving characteristics of the conventional double crib with inside elevator. We can profitably make a more thorough study of the value of cobs as a part of cattle rations and the possibilities of obtaining equivalent results with some other form of roughage.

Effective feed-handling systems. A major reason for livestock enterprises being below crops with respect to productivity of labor is the inflexible nature of buildings, their relatively long life, and the difficulty of planning completely integrated production centers. We are in the position of being able to tackle this problem while less than 1 percent of the farmers have committed their resources to shelled corn systems. We need to be prepared to furnish guidance and provide adaptable facilities as farmers change methods of handling corn. This is a major responsibility as nearly 90 percent of all corn is ultimately used for livestock feed.

Shelled corn approaches a fluid condition and can be handled readily with mechanical equipment and gravity flow systems. Most farmers have suitable means for moving corn through the drier and into storage. Generally, only makeshift arrangements are available for handling the corn once it has been placed in storage. Specially designed units for handling and processing feed should be made available to farmers or carefully prepared plans should be developed as guides in establishing their feeding systems instead of requiring farmers to rely on their own ingenuity for rigging labor-saving feed-handling systems. Some research has been done by the agricultural engineers at the University of Illinois in developing low-cost automatic units for mixing, grinding, and transferring feed to the feeding area. Similar units are on the market at present, but in most instances, they require custom installation.

An effective unit need not include automatic equipment. A simple gravity flow system may be quite adequate. Further research is needed, however, to outline major alternatives for handling livestock feeds.

Marketing implications. The marketing implications of field shelling and artificial drying of shelled corn have been relegated to the background in our considerations of the development and application of field machinery. Yet this is one of the most important economic aspects of the entire development. We must at least be acquainted with some of the marketing problems before we can fully appreciate the significance of the developments we are discussing at this conference.

We have mentioned some of the problems of marketing dried corn to the milling industry. These problems are important but technical developments should serve to iron out difficulties in this area. I am concerned at the moment with the possible effects on the entire marketing system.

One of the advantages that we sometimes list is the possibility of a premium price for dry corn or for selling new corn at old-corn prices. Not all farmers or elevators are able to take advantage of this opportunity. Elevators that do not have the facilities to blend corn may realize no gain from handling dried corn. With volume marketings of dry corn at harvest, this could become a penalty rather than a premium period.

Drying corn artificially may change the seasonal pattern of marketing. From 1949 through 1954, monthly marketings of corn in Illinois averaged 13 percent in October and 14 percent in November with from 6 to 8 percent sold in each of the remaining 10 months. The major burden of financing and storage of market as well as feed corn has obviously been carried by farmers. During these same years, 64 percent of the soybean crop was sold from September through November with 40 percent marketed in October. Eighty percent of the Illinois wheat crop is sold in July. If we get more of the corn crop in condition to market at harvest, it is possible that a much higher proportion of the crop may be sold at that time, thus developing more of a peak pattern as with soybeans and wheat.

Illinois farmers produced 100 million bushels of soybeans and 51 million bushels of wheat in 1955. Practically all of these two crops was sold. Production of corn for 1955 was 524 million bushels with about half the crop going to market. These figures show that even small increases in the proportion of corn sold at harvest will put an extra strain on the already overloaded storage and transportation facilities of the grain trade. The tendency to harvest corn earlier in the year and thus to overlap more of the soybean harvest complicates the situation even further.

One possible outcome of peak marketings is greater seasonal price differences, which may induce farm storage. Expansion of facilities within the grain trade is also a possibility. If such an expansion occurs, the belief has been expressed by some marketing authorities that the small elevators might not be able to bear the financial burden of an expansion program, thus concentrating business with the large concerns.

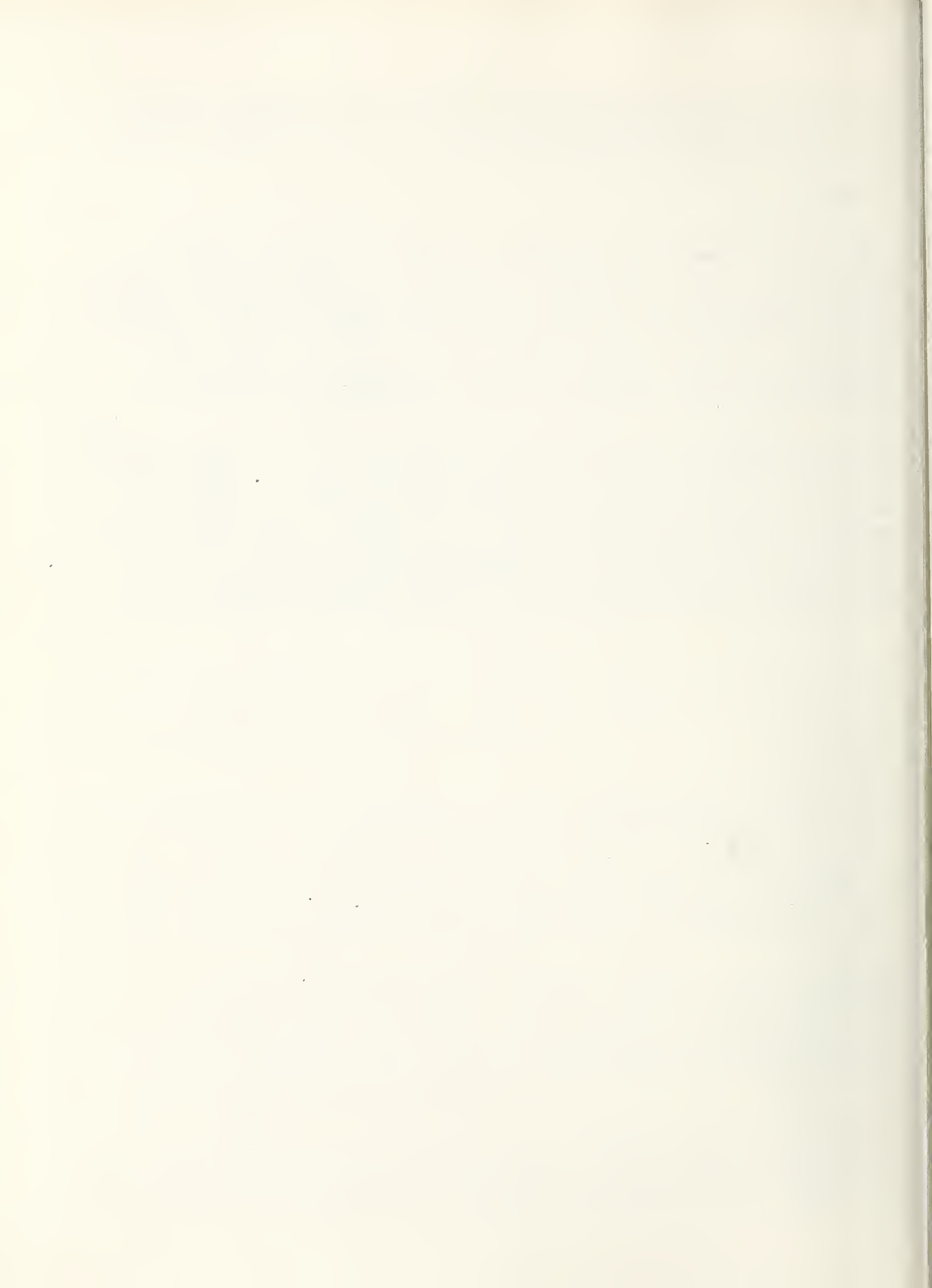
We have no assurances that any of these possibilities will develop or that factors not yet considered may become important. We can expect that any changes in the marketing system that are required to meet new developments in harvesting will take time and will meet with resistance, as any change

involves risk. There are no definite answers at this time but it is evident that marketing problems are important from the viewpoint of both the individual farmer and the grain trade.

Summary

The developments and possibilities of harvesting, drying, and storage of shelled corn discussed at this Conference have aroused much interest in many fields. Final effects may be as important as those from any development since the combine. However, changes will probably be gradual. Most farmers have high fixed investments to which change would only add costs. They are familiar with existing methods and they have been reasonably successful. A real and urgent need will be required to bring about a change in most cases. Also, the possible advantages of new methods of harvesting do not have the same worth for every farmer.

We all have a part in this development which promises to be basic to Corn Belt agriculture. We can look ahead instead of backward. Through cooperative efforts toward solving both engineering and economic problems, we should someday be able to look backward with pride. We in Economics have enjoyed a close working relationship with the subject matter specialists, the agricultural engineers, and industry people in particular. We are looking forward with anticipation to cooperating in future growth and development of methods for harvesting, storage, and utilization of corn.



THE STATUS OF PUBLIC RESEARCH
ON PICKING AND SHELLING CORN 1/

by

L. W. Hurlbut, Chairman,
Department of Agricultural Engineering
Univ. of Nebraska, Agricultural Experiment Station

The complexity of the corn production process is fairly well indicated by the number of agricultural and engineering sciences concerned with it. These include agricultural engineering, agronomy, entomology, plant pathology, animal nutrition and agricultural economics. The breadth of the research work done in all of these fields makes it almost impossible to identify clearly, and review, all of the public research that now has some relationship to the modern corn production process. Reports on the important work being done in several of the agricultural sciences will be discussed sometime during this conference. At this time, my job is to summarize the agricultural engineering investigations directly concerned with the picking and shelling of corn.

PICKING CORN

Several different kinds of machines are currently available for use in harvesting corn. These are generally identified as: pickers (or snappers); picker-huskers; picker-shellors or picker-threshers; and picker-choppers (introduced in 1954). The picker unit is an important part in each of these machines. The ears are harvested by the picker and then conveyed to either a wagon or a processing unit of some kind. There are a few new machines which cut and "thresh" the entire corn plant.

The importance of the mechanical corn picker is clearly indicated by its use in practically all modern corn harvesting machines. Its importance is also reflected in the research and field testing investigations that have been completed, or are now underway at public research stations.

Growth in use of the mechanical corn picker can be closely related with certain other mechanical developments and with certain periods of high demand for labor. Their numbers expanded fairly rapidly in the late 1920's parallel with the expansion in use of the tractor power-takeoff. During and immediately subsequent to World War II the high demand for labor was another cause for rapid expansion in the use of the corn picker. It is important to realize that less than 15% of the total corn crop was harvested mechanically in 1938 (2). By 1951, about 90% or more of the total acreage of corn in each of the seven corn belt states was being harvested mechanically; whereas, only about 68% of the total corn acreage in the United States was being harvested in this manner.

There are some differences in explanations as to why there was expanded use of the mechanical picker. One group of investigators (27) say that its use can be attributed to several factors, but point out that it coincides rather closely with the development of hybrid seed corn. Their data failed to show any advantage in harvesting efficiency of the mechanical corn picker through the use of double-cross hybrid seed corn as compared with two open-pollinated

1/ Paper No. 776, Journal Series, Nebraska Agricultural Experiment Station.

varieties. They reported data from replicated harvesting tests made with 20 commercial hybrids and two open pollinated varieties under highly favorable harvesting conditions. They report that as an average, the hybrids failed to give better picker results than did the varieties. And, the crop delivered by the picker contained 11.1 percent shelled grain as an average for the hybrids and 6.5% for the varieties. As a straight average, the 20 commercial hybrids yielded 13.5% more grain than did the varieties. More broken and leaning plants were found in the open pollinated varieties. The chief advantages shown for double-cross hybrid seed corn appeared to be higher yields and more erect stalks.

The test reports indicate, in general, that the harvesting losses may be equal to or greater than the increase in yield that can be expected from the use of hybrid seed corn over open pollinated varieties.

Field tests of hybrids made by agronomists generally contain gross yield. Judgement as to the amount of ear droppage and stalk breakage is made early in the harvest season. There is a lack of data on the mechanically harvested yield of different hybrids throughout the harvest season.

Some authorities (15) believe that the effect of hybrid seed corn has been less important in increasing both profits and acreage (in the State of New York) than has the adoption of the corn picker. In New York it was found that although corn yields on cost account farms showed little change over the years, there was a striking decrease in the hours of labor required coupled with an increase in the net income from corn. Hurst and Church (13) seem to support the latter thinking by their estimate that the labor required to produce an acre of corn yielding 40 bushels dropped from about 15 man hours per acre with hand harvesting around 1900 down to about 7 man hours per acre or less in 1930 with the mechanical harvesting equipment then available. Shedd, et al, (25) in 1937 estimated the annual productive capacity of one worker to be 5000 bushels or more. He also estimated that less than 10 man-minutes per bushel might be required with the two row mechanical picker and efficient hauling and elevating equipment.

Field test reports based on the harvesting efficiency of the mechanical corn picker extend over a period of more than 25 years. Some data from a number of the published reports on the efficiency of mechanical corn harvests are tabularized in Tables I and III. These test data clearly show that the highest harvesting efficiency is obtained early in the harvest season and that the harvesting efficiency decreases rapidly as the season progresses. The minimum field loss (percent of total yield) to be expected under favorable harvesting conditions, in relation to moisture content of the kernels and cobs, is estimated in Table II. With less favorable harvesting conditions the harvesting efficiency of the corn picker may be 2 to 3 times the minimum expected losses shown in Table II. The increase in losses may result from different combinations of factors involved in weather hazards, insect damage and varietal characteristics.

Rossman and Woods (24) (Michigan) studied six rates of planting in relation to picker losses. The losses averaged 6.0, 6.9, 10.3 and 13.4% of the total yield for plant populations of 10,300, 14,900, 18,900 and 22,900 plants per acre. Lodging and stalk breakage increased from 8 to 33%.

Table 1.--Field Losses Reported for Pickers and Picker Huskers

State	Year	Kernel Moisture %	Total Harvest Loss		Yield Bu/A
			Range	Average	
Iowa (5)	1928-31		.5-20.5%	8.1%	
Illinois (33)	1929		2 - 24.9%	10.2%	57
Illinois (33)	1930		6.4-39.1%	12.5%	47
Iowa (25)	1931	20.2-17.7	9.1-19.3%		63-75
Iowa (25)	1932	19.8-17.4	11.5-15.7%		65-69
Iowa (25)	1933	16.6-15.7	9.3-10.3%		78
Texas (28)	1948	16.7-11.1	2.7-15.9%		35-42
Nebraska (27)	1948	24 - 14	2.8-13.4%	8.6%	89.9
Nebraska (1)	1950	25.2-18.8	3.3-10.2%		75-85
Nebraska (1)	1951	27.5-19.7	2.4-9.1%		90-115
Alabama (3)	1953	27 - 14	.85-8.65 bu/A		75-
Alabama (3)	1954	19 - 14	1.2-2.4 bu/A		66
Alabama (3)	1955	19 - 15	3.8-11.2 bu/A		94

* * * * *

Table 2.--Expected Total Field Loss (percent) of Corn Harvested Under Favorable Conditions in Relation to Moisture Content of the Kernels and Cobs (11).

Days after Maturity							
Crop characteristics	Mature	10	20	27	34	41	49
Kernel moisture	34	26	20*	17.5	16	15	15
Cob moisture	54	46	30	24	21	19	17
Expected crop loss	1	2	4	7	10	13	15

* * * * *

Table 3.--Field Losses Reported for Picker-Shellers and Picker-Threshers.

State	Year	Kernel Moisture %	Total Harvest Loss	Yield Bu./A
Illinois (26)	1942	24.7-17.3	1.12-6.37 bu./A	41.3-43
Indiana (4)	1950	24.9	8.48 bu/A	66.6
Nebraska (1)	1950	25.2-18.8	3.34-10.2%	65-85
Indiana (4)	Oct. 25-Nov. 23, 1951		10%	
Indiana (4)	Dec. 7, 1951		24%	
Iowa (31)	1951	25 - 17	12.98-14.38%	
Nebraska (1)	1951	27.5-19.7	2.4-9.10%	100-125
Minnesota (29)	1953	31 - 19	4.3-12%	
Minnesota (29)	1954	35 - 23	20%	
Nebraska (16)	1954	25.1-15-9	10-24.5%	85-100
Iowa (9)	1954			
California (8)	1954	18.5-12		
South Dakota (7)	1954	23%	11.4%	69.8

* Normal harvest starts at a kernel moisture of 20 percent.

Wileman (32) mechanically picked 9 open pollinated strains and 22 hybrids known to vary in height of ear, length of earshank, and earshank diameter. He found that as earshank diameter increased there was a decrease in average picker loss (% of total yield).

Chaing and Hodson (6) report the results of studies in Missouri on the effect of artificial stalk breakage on ear growth; the effect of borer population on stalk breakage and ear dropping; seasonal occurrence of stalk breakage and ear dropping; and the efficiency of the mechanical picker in broken stalks.

Shedd, et al, (25) in 1937 pointed out the basic problem with the mechanical corn picker as being "the amount of corn left in the field." This remains to be the basic problem. While an early harvest is one way of reducing field harvesting losses, it is believed that this factor alone is not the ultimate solution to the problem of reducing harvesting losses.

FIELD SHELLING CORN

Picker-shellors first became available during the middle 1930's. Some attempts to harvest corn with small grain combines were made in the late 1920's and early 1930's.

In 1924 George Iland (Australia) adapted a horsedrawn small-grain combine to harvest corn. The Director of Agriculture in Australia (22) observed it and reported "The opinion formed after a close examination of the machine and the excellent work accomplished under average working conditions, was that this complete harvesting device will not only reduce maize harvesting costs to a minimum, but will eventually prove to be one of the most notable inventions of all times." This machine was reported to harvest 360 bushels of shelled maize in $8\frac{1}{2}$ hours in corn yielding 60 bushels per acre. It was suggested that the rows of corn be planted around the field to make the harvesting more continuous.

Some of the earliest reported attempts to use the small-grain combine for harvesting corn were made in Iowa (19) in 1928, and in Nebraska (19) and Kansas (18) in 1930. These attempts were made in the late winter or early spring when harvesting conditions are well-known to be poor.

While the conditions during the experimental harvests were far from ideal, there was general agreement on the following points:

1. The equipment used for gathering the corn stalks and attached ears onto the platform, and for conveying them to the threshing cylinder needed much improvement.
2. The threshing operation was quite satisfactorily performed. The cracking of kernels was considered not to be excessive and the kernels, with approximately 18.4% moisture, were practically all removed from the cobs.
3. There seemed to be no great difficulty in separating the kernels from the larger mass of shredded stalks.
4. Mechanically the corn combine was considered to be past the experimental stage.

5. It appeared that the universal use of the combine for harvesting corn would depend upon ways and means for getting the shelled corn conditioned for safe storage.

The substantial progress which has been made recently in developing improved methods and equipment for drying small grain and shelled corn has accelerated both the public and industrial interest in equipment for field shelling corn. The new industrial interest became apparent in 1954 with the appearance of a self-propelled thresher with overall width less than 80 inches equipped with a 2-row picker attachment.

Comparison of Methods of Harvesting Corn. Skelton and Bateman (26) (Illinois) made a very extensive test of a 2-row pull-type picker-sheller in 1940. Two men with this machine and a truck harvested 10,000 bushels of corn from 291 acres in 215 field hours between October 21 and December 10. The yields ranged from 24 to 56 bushels per acre. The hourly output of shelled corn ranged from 33 to 75 bushels. The grain moisture ranged from 23% down to 17%.

In making comparisons of the picker sheller with one-row and two-row picker methods of harvest, they summarize their report as follows:

1. The lower cost of the field shelling as compared to present methods for areas greater than 45 acres results from combining the picking and shelling operations, reduced hauling costs, greater capacity of the machine, and smaller power requirements.
2. The greatest portions of the harvest losses in fields yielding up to 66 bushels per acre was caused by the snapping rolls and gathering points. (The picker losses ranged from 1.09 bushels/Acre up to 6.18 bushels/Acre. The shelling losses ranged from 0.07 bushels/Acre up to 1.02 bushels/Acre.)
3. Foreign material and damage caused by operation of the machine did not result in a reduction in market grade.

The remarks of Martin Ronning (23) in his discussion of the report made by Skelton and Bateman set forth clearly and concisely the general thinking of the machinery manufacturers up until very recently. He said:

"In our company, we have not made a detailed study of the problem of shelling corn in the field because we have believed this method to be rather impractical due to the uncertain weather conditions during corn harvest, resulting in a serious problem of storage of the shelled corn. However, I do not think this method is hopeless and not deserving of study. It must be remembered that at one time there was a doubt as to the practicability of the combine for use in the Middle West; in fact, there are some communities where the farmers still feel that way about it.

From the standpoint of the machinery designer, the field shelling of corn is not particularly difficult. The job can be done either with a modified combine or by a corn picker with a corn shelling attachment. The main problem, as I see it, is that of taking the corn from the field with a moisture content safe for binning, which should not exceed 14 percent.

The agronomists have done such wonderful things in hybrid development in recent years, that it is possible they will develop hybrids that can be depended upon to mature to a safe binning moisture content earlier than the present hybrids, thus giving the farmer a safe margin of time to get his corn harvested under normal weather conditions.

It is also possible that something can be done in the way of bin ventilation to handle safely corn with a greater moisture content. Or possibly artificial drying may be resorted to, although the cost would probably be prohibitive.

It seems reasonable that before any sweeping change in farming procedure of any kind can come about, there must be a definite economic reason for so doing, and if there is coupled with this a definite relief from drudgery, as in the transition from the grain binder-thresher method to the combine, the evolution is bound to be quickly accomplished.

It does not seem, however, that a great saving would result from field shelling of corn, nor would there be much lessening of disagreeable labor involved. We must also bear in mind that the corn grower, who now owns a corn picker and who has a good corncrib on his farm, in which he can crib his corn with a feeling of safety, would not readily discard his picker for a field shelling machine and replace his corncrib with a bin for shelled corn."

Your speaker hear remarks similar to those of Mr. Ronning's repeated several times during 1949 when personal interviews were held with engineers engaged in the machinery industry. The interest of industry in the development of field shellers was found to be at a very low ebb at that time. Since 1949 the results of public research work related to the improvement of the corn harvesting process have helped a great deal to reduce some of the problems which were blocking the use of a harvesting procedure which was demonstrated by Iland in Australia, and by Skelton and Bateman in Illinois, to have many basic advantages.

Herum and Barnes (9) (Iowa) selected five different harvesting methods for comparison. They were:

1. The conventional method using a mechanical picker-husker. The kernel moisture was considered to be 20 percent, and the corn was stored in a crib until it was either fed or shelled.
2. Picking with the picker-husker at 26 percent moisture and drying artificially in a crib with heated air.
3. Picking with a corn picker at 30 percent moisture, processing the corn with a stationary ensilage cutter and ensiling.
4. Using a picker-sheller at a kernel moisture of 25 percent and drying with heated air.
5. Using the picker-sheller at 26 percent moisture and ensiling the shelled corn.

They concluded that when the harvested acreage is above 125 acres per year, the picker-sheller-dry-bin method is less expensive than the methods requiring the cribbing of corn. The decrease in storage costs makes up a great part of this saving. However, field losses contribute to total harvesting costs in amounts which may equal the sum of all other harvesting costs.

The Small Grain Combine for Harvesting Corn. In considering the corn harvest from the standpoint of farmers who diversify the production of grain crops, the ideal harvesting machine should: be versatile enough to harvest the corn crop as well as the small grain crops; pick up fallen ears; collect all shelled corn; be easily and safely operated. Versatility in the use of structures for grain and seed storage appear to be about as important as versatility in the use of the harvesting machine.

Work was started in 1950 at the Nebraska Agricultural Experiment Station on an experimental ear-corn harvesting attachment which would mount on the platform of a combine. It is intended that this arrangement would eliminate the loss of shelled corn at the snapping rolls and also move the stalk laterally so that there would be a better chance to pick up loose ears. The device is designed so that the incoming cornstalks pass between two inclined gathering points equipped with standard lug-type gathering chains. The stalks are then cut by the combine sickle, and as they move rearward of the sickle they encounter notches in a forked arm which steady the severed end of the stalks until a short auger forces them between the snapping rolls. The snapping rolls are located rearward of the cutterbar and directly above the platform canvas. One roll is set above the other, the lower roll being enough longer than the upper roll to provide for a short section of auger which forces the stalks between the snapping rolls. The snapping rolls are set at an angle (about 30 degrees) to the row so as to cause the stalks to travel away from the row while at the same time they travel forward between the snapping rolls. The stripped stalks are ejected forward over the cutterbar onto the ground. The ears, and most of the corn that is shelled by the snapping rolls, will fall onto the platform. The elevator canvas is equipped with enlarged slats so that it can convey the ears and the shelled corn to the threshing cylinder.

Pickard and Bateman (20) (Illinois) in 1953 started experiments with a combine with a gathering and feeding device to harvest one row of corn and put the entire plant through the machine. The principle results of this work was to confirm the belief that the cylinder and cleaning shoe of the combine are adequate for shelling and cleaning corn and the combine does not easily handle the entire corn plant. Goss, et al, (8) (California) made field tests of the effectiveness of two self-propelled combines equipped with rasp bar cylinders. One combine gathered the whole stalk and threshed it. The other combine had a snapping roll gathering unit attached ahead of the cylinder. The tests indicated that the ordinary grain combine is well suited for shelling corn under California conditions.

Limits on Early Harvest. From the mechanical standpoint the limit on early harvest depends upon shelling loss and mechanical damage to the kernels. The limits on these factors come at a moisture level which is lower than the moisture level at which the kernel ceases to gain weight by normal growth processes.

Hurlbut, et al, (12) in 1948-50 found that corn shellers would do a reasonably good job in shelling corn containing 28% moisture. In trying to establish the earliest practical harvesting time for existing machines an "improvised" trailer sheller was used for shelling corn containing up to 30% moisture. Burrough and Harbage (4) tried a field sheller in corn containing 34.5% moisture with very poor results. Tests at 29.6% moisture indicated that from 5 to 10% of the total yield was being left on the cob and about 14.5% of the kernels were damaged. At 20% moisture, only about 4% of the kernels showed damage. Herum and Barnes (9) found that picker-sheller losses decreases as the kernel moisture drops from 30 to 25 percent. Further drying results in increased ease of shelling and consequent increase in losses of shelled corn at the snapping rolls. Kitchen and Nelson (17) found that a commercial picker-thresher would begin to do a satisfactory job of shelling corn near the 26% moisture level. They found that corn borer damage in the cob adversely affected the shelling efficiency of the threshing cylinder. W. H. Johnson (14) (Ohio) found kernel damage was 12-19% with kernel moistures ranging from 25-30%. The damage ranged from 2-6% with a moisture range of 15-20%. Strait, et al (29) (Minnesota) report that corn harvested with a kernel moisture content of about 25% or less and with reasonable machine adjustments should grade No. 2 or better as far as the percentage of cracked corn, foreign materials, and damaged kernels are concerned. Sheller losses will generally not exceed 2 percent. For feed grain, the harvesting may be started at a moisture content of about 28 percent. The sheller loss amounted to as much as 3 percent of the crop at a (kernel) moisture content of 30 percent. The kernel damage met the grade requirements for No. 1 corn with the moisture at the 19% level or less. Frozen corn shells very well. Shelling was complete and damage to the kernels was negligible over the entire range from 40 to 18% kernel moisture.

Thresher Cylinder Speed and Kernel Moisture. Pickard (21) has reported laboratory studies of six combinations of cylinders and concave bars. Cylinder clearance, kernel moisture, cylinder speed and ear orientation affect the shelling efficiency and kernel damage. The comparisons based on kernel moisture variations show that both kernel loss and kernel cracking are high at the 30% moisture level. The corn loss approaches the minimum slightly above the 25% moisture level. A cylinder speed of 800 rpm (3100 fpm) is more desirable than a speed of 600 rpm (2350 fpm). Goss (8) et al, (California) made field tests with a self-propelled combine equipped with a stalk-gathering attachment and a "straight-through type" with an ear snapping attachment. Corn (13 to 15.2% moisture) shelled at a cylinder speed of 3800 fpm or less with the self-propelled combine graded No. 2 or better. The straight-through combine with a cylinder speed of 2900 fpm or less harvested corn containing 2% or less of cracked corn and foreign matter.

Investigations Now Underway. Agricultural Engineers at public research stations are continuing their steady search for ways and means for improving the mechanical efficiency and labor efficiency of the corn production process. They are also seeking to reduce the physical effort involved, to insure the quality of the grain after it is placed in storage, and to get more effective use annually from the harvesting equipment and storage structures.

A View of the Future. It is well known that changes in farm production practices are intertwined with economic elements, technological advances and political measures. With this in mind, and as we now stand at the beginning

of another step forward in the mechanization of corn production, let's glance backward for a moment and see how one agricultural economist in the USDA sized up the census data of about two decades ago. He says:*

"The invention of farm machinery and the application of animal and later mechanical power to agriculture have brought about a great economic revolution. During the century ending in 1930 a threefold increase in production per worker in agriculture took place in the United States as a result of science and invention. Possibilities in the use of agricultural machinery are as wide as ever before, but the future is so clouded by social and economic developments -- that it is impossible to estimate with confidence how long the present upward trend in the use of farm machinery will continue."

This is a statement that withstands perpetual useage. Certainly it is designed to give comfort to the pessimists who are experiencing a lifetime of continuous change and progress.

* USDA Miscellaneous Publication No. 264, July 1937.

BIBLIOGRAPHY

1. Arms, M. F., University of Nebraska, Unpublished Data.
2. Brodell, A. P. and Walker, H. R., USDA Statistics Bulletin 129:1-10, 1953.
3. Butt, J. L. and Helms, J. O., Comparative Yields of Early and Late Harvested Corn, Progress Report Series No. 63, March 1956, Alabama Agricultural Experiment Station.
4. Burrough, D. E., and Harbage, R. P., Performance of a Corn Picker Sheller, Agricultural Engineering, V-34, January, 1953.
5. Carter, W. H., Comparative Effectiveness of Hand and Mechanical Corn Picking. Agricultural Engineering, V-12, No. 7, July, 1931.
6. Chaing, H. C. and Hodson, A. C., Stalk Breakage Caused by European Corn Borer and Its Effect on the Harvesting of Field Corn, Missouri Agricultural Experiment Station, Journal of Economic Entomology, V-43, No. 4, pp 415-22, August, 1950.
7. Delong, H. H., Picker-Sheller and Cold Air Drying, South Dakota Agricultural Experiment Station Farm and Home Research 6:91, Summer 1955.
8. Goss, J. R., Bainer, Roy, Curley, R. G., Field Tests of Combines in Corn, Agricultural Engineering, V-36, December 1955.
9. Herum, F. L., and K. K. Barnes, Iowa Agricultural Experiment Station Farm Science, 9:519-20, July 1954.
10. Hopkins, D. F., and Pickard, G. E., Corn Shelling With a Combine Cylinder, Agricultural Engineering, July, 1953.
11. Hurlbut, L. W., How Efficient Is Your Corn Harvest, Nebraska Agricultural Station Quarterly, Fall 1952.
12. Hurlbut, L. W., Petersen, G. M., Yung, F. D., Olson, E. A., Harvesting and Conditioning Grain for Storage, Agricultural Engineering, V-33, No. 7, pp 421-425, July 1952.
13. Hurst, W. M., and Church, L. M., Power and Machinery in Agriculture, USDA Miscellaneous Publication 157, 1933.
14. Johnson, W. H., Ohio Agricultural Experiment Station, Unpublished Data.
15. Kearl, C. D., Cornell Agricultural Extension Farm Economics 182:1854-6"0", 1951.
16. Kitchen, D. A., and Nelson, Roger, University of Nebraska, Unpublished Data.
17. Kitchen, D. A., and Nelson, Roger, Unpublished Data, University of Nebraska, Department of Agricultural Engineering.

18. Logan, C. A., The Development of the Corn Combine, Agricultural Engineering V-12, July 1931.
19. McKibben, E. G., Harvesting with a Corn Combine, Agricultural Engineering, V-10, July 1929.
20. Pickard, G. E., and Bateman, H. P., Corn Shelling with a Combine, Agricultural Engineering 35:500, July 1954.
21. Pickard, G. E., Laboratory Studies of Corn Combining, Agricultural Engineering, December 1955.
22. Quodling, H. C., Queensland Agricultural Journal, New Series, V-21 and 22, October 1924.
23. Ronning, Martin, Discussion of Paper on Picker-Sheller, Agricultural Engineering, April 1942.
24. Rossman, E. C., and Woods, D. J., Stand and Corn Picker Losses Compared (Michigan State University) Crops and Soils 8:25, 1955.
25. Shedd, et al, Labor, Power and Machinery in Corn Production, Iowa Agricultural Experiment Station Bulletin 365, September 1937.
26. Skelton, R. F., and Bateman, H. P., Field Shelling of Corn, Agricultural Engineering, V-23, No. 4, April 1942.
27. Smith, C. W., Lyness, W. E., Kiesselbach, T. A., Factors Affecting the Efficiency of the Mechanical Corn Picker, Nebraska Agricultural Experiment Station Bulletin 394, September 1949.
28. Smith, H. P. and Sorenson, J. W., Mechanical Harvesting of Corn, Texas Agricultural Experiment Station Bulletin 706, 1948.
29. Strait, John, Keppel, R. V., Meyer, V. M., Harvesting Corn with the Picker Sheller, Minnesota Farm and Home Science, Vol. XII, No. 3, May 1955.
30. Strait, John, Keppel, R. V., and Meyer, V. M., Harvesting Corn with the Picker Sheller, Minnesota Farm and Home Science, May 1955.
31. Van Vlack, C. H., and Beresford, Hobart, The Picker Sheller--Its Advantages and Disadvantages, Iowa Farm Service, Iowa State College, July 1953.
32. Wileman, R. H., The Effect of Corn Plant Characteristics on Mechanical Corn Picker Loss, Agricultural Engineering, V-14, May 1933.
33. Young, A. L., Present Status of Mechanical Corn Picking, Agricultural Engineering, V-12, No. 7, July 1931.

STATUS OF RESEARCH ON FARM DRYING OF SHELLED CORN

Wallace Ashby
Agricultural Engineering Research Branch,
Agricultural Research Service, U. S. Dept. of Agriculture

The purposes of this paper are (1) to give a bird's-eye view of the extent, variety and importance of research problems related to drying and storing field shelled corn, (2) to report briefly on problems that are being studied and (3) to list publications where further information may be found.

Problems Differ by Regions

Corn is grown in every State in the Union. While the heaviest concentration is in the North Central States, there are large acreages in the East and South, and the acreage on the West Coast is increasing rapidly.

In a normal season corn picking begins in southern Texas in early August. Along the Canadian border it begins about October 1. In the central Corn Belt picking usually begins during the last 10 days of October unless the corn is to be dried mechanically. Thus weather at time of harvest varies from summer conditions in the south to early winter conditions in the north.

Weather variables that affect corn ripening include temperature, relative humidity, rainfall, sunshine, wind, soil moisture and others. The columns in Figure 1 represent a drying rate index^{1/} based on the combined effects of temperature, relative humidity and wind. The column on the right at each location represents the index when corn picking ordinarily begins. The middle column represents it two weeks earlier and the left-hand column four weeks earlier. The higher the column the faster the drying in the field. The rate of field drying when harvest begins is high in the Southwest, moderate in the North Central States, and low along the East and Gulf Coasts. It is low along the North Pacific Coast also.

Figure 2 compares the air temperatures and relative humidities at the same stations and dates as in Figure 1. In an ordinary season little difficulty is met in drying corn mechanically with natural air near Des Moines, Iowa or Lincoln, Nebraska, partly because temperatures at harvest-time are below 65° and therefore molds and fungi do not grow rapidly. On the other hand, drying corn mechanically with unheated air at Holland, Virginia is difficult, presumably because both the temperature and the relative humidity at harvest time are high enough for rapid developments of molds. There is much less difficulty in drying corn with natural air at Athens than at Holland. Although the temperature is higher at Athens, the relative humidity is slightly lower. We have no experience in drying corn at Lake Charles.

^{1/} Estimated from Fitzgerald's equation, evaporation in inches per day = $(.4 - .199 W) (P_s - P_a)$, where W = wind in miles per hour, P_s = saturation vapor pressure and P_a = actual vapor pressure in inches of mercury. (From Hydrology, Wisler, C. O., and Brater, E. F., John Wiley & Sons, 1949)

While these slides point out some of the differences between locations, the relation of climatic conditions to field and bin drying potential is not well understood and considerable more work on this important subject is needed. (See Peterson and Simons, p. L and Barre, p. M of these Proceedings).

Influence of Insects. The European corn borer, which is now found throughout the Corn Belt, is one of the reasons for harvesting corn as soon as it is matured. The longer corn attacked by borers stands in the field the more ears fall to the ground and cannot be recovered by mechanical harvesters.

The Angoumois grain moth is another insect that causes serious damage to the corn crop, both in the field and in storage. Moth damage also is reduced by harvesting early. The area of serious Angoumois moth infestation is roughly the part of the country south of U. S. Highway No. 40, which runs through Baltimore, Maryland; Columbus, Ohio; St. Louis and Kansas City, Missouri, and west to San Francisco.

In regions having heavy Angoumois moth infestation, insect damage to ear corn far exceeds that to shelled corn during storage.

PUBLIC RESEARCH RELATED TO FARM DRYING AND STORAGE OF CORN^{2/}

Agencies for public research in farm drying and storage of corn are the Agricultural Research Service of the U. S. Department of Agriculture and State Agricultural Experiment Stations. They cooperate in much of their research for greater effectiveness and to avoid duplication of effort. Work of the Agricultural Marketing Service, U.S.D.A., the U.S. Weather Bureau, and other agencies also contributes to solution of corn drying and storage problems.

While the major responsibility for developing drying and storage principles and techniques falls in the field of agricultural engineering the problem reaches into the fields of botany, agronomy, plant pathology, entomology, biochemistry, nutrition, farm management and economics. Each of these fields is represented in the Agricultural Research Service and/or the State Agricultural Experiment Stations.

Measurement of Moisture Content. This is one of the things that is giving farmers serious trouble because a reasonably accurate knowledge of moisture content is essential in deciding when to harvest shelled corn, the rate of air flow needed for satisfactory drying, the depth or thickness of layer that can be dried with a given fan, and when to stop drying. Part of the farmer's difficulty is no doubt due to lack of care in drawing representative samples for the moisture test, but part is due to lack of low-cost equipment for obtaining accurate moisture readings. To be satisfactory an instrument for farm use should give readings that are accurate within $\frac{1}{2}$ or 1 percent for dry corn (12% moisture) and within perhaps 2 percent for wet corn (30% moisture).

^{2/} The list of literature cited is not complete as many State and other publications were not readily available when the list was prepared.

Methods of measuring moisture in grain are studied by the Standardization and Testing Branch, Grain Division, Agricultural Marketing Service, of the U. S. Department of Agriculture. These studies are concerned with chemical, oven and electrical methods. (1) The Branch has found that moisture meters actuated by electrical resistance are satisfactory with corn of up to 23% moisture content provided the moisture is uniformly distributed in the kernels. Such meters are not accurate at higher moisture contents or within 12 hours after drying, when the outside of the kernels is drier than the inside. Meters of this type then read too low and may be seriously in error. For a correct reading it is necessary to allow the corn sample to temper in a sealed container at room temperature for 12 to 24 hours after drying. Moisture meters actuated by the electrical capacitance of the grain are not much affected by uneven distribution of moisture in the kernel. However, none of the electrical moisture meters tested that cost less than \$80 gave satisfactory results.

Another type of moisture testing apparatus distills off and measures the moisture in a weighed sample of grain. A reliable single unit of this type costs about \$40. It gives accurate results but requires about 20 minutes per sample.

Other testers dry the sample with infrared heat and read the difference in wet and dry weight to determine the moisture content. A good tester of this type costs about \$100 and requires about 15 minutes per test.

The method of weighing the wet grain, driving off the moisture with heat, then weighing the dry grain and calculating the moisture content, may be used with improvised equipment. Any source of heat may be used, such as the tractor exhaust, a hot oven or boiling oil. (32) The objections are the time required, the need for accurate weights, and the risk of charring the grain if dry heat is used.

Improvement of the Corn Plant. The Agricultural Research Service and many of the Agricultural Experiment Stations are developing types of corn that are resistant to disease and suitable for mechanical harvesting; that is, they remain upright with the ear attached and have a husk that can be removed easily and cleanly without use of excessive power. (2)

The relation of moisture content to maturity has been studied by several State Experiment Stations. (See Miles, p. G of these Proceedings).

Control of Insects. The Agricultural Research Service and cooperating State Experiment Stations are carrying on work to control insects in the field through better insecticides and methods and equipment for applying them. (3) The Agricultural Marketing Service and cooperating State Stations are conducting research on the control of insects attacking stored corn. (4, 5)

Research on Farm Drying of Shelled Corn

Research on drying corn is much like an iceberg which has 80% of its bulk out of sight. It is based on scientific data worked out over a period of years before anyone thought of drying corn on the farm.

While seed corn has been dried mechanically on the ear for nearly thirty years and shelled corn has been dried at elevators for an even longer period, farm drying of shelled corn has developed during the past 10 years.

There are several possible ways of drying shelled corn. One way is to bring it in contact with a dry material that will absorb part of the water, as is done when dry and wet grain are blended at a grain elevator. It might be dried in a vacuum oven or by dielectric heating, or by squeezing moisture out in a press. However, the only way that corn is being farm-dried successfully is by forcing air through it. The process rests on well known properties of air and water vapor and principles of heat transfer that are presented in standard engineering handbooks. (6,7) Drying of corn is similar to drying of other hygroscopic materials. However, to design an economical drying system for corn, specific information is needed about the corn kernel as a single unit and in bulk.

Following is a brief review of the status of research on some of the important factors affecting drying.

The Equilibrium Moisture Content, that is the moisture content that the corn kernel will reach if fully exposed to air of known temperature and relative humidity is a factor in the rate of drying and the safe moisture content for storing corn. Valuable data are available though more complete information is wanted. (8,9)

Amount of Moisture to be Removed depends on the moisture content of the corn at time of harvest and the use to be made of the grain. If for seed or for long time storage, it should be dried to 11% - 12% or perhaps lower moisture content in hot climates. If it is to be sold on the market immediately after drying, 15- $\frac{1}{2}$ moisture corn will bring as good a price as if it were drier, and there is less loss of weight. If it is to be fed immediately, even higher moisture may be permissible.

The amounts of water per bushel in corn of different moisture contents are available for both shelled and ear corn. (10, 11, 12, 13 and Mitchell, p. N of these Proceedings). Since the moisture in the cobs at the end of the growing season is higher than in the kernels, considerably more water must be removed from ear corn than from the corresponding amount of shelled corn if both lots are dried to the same kernel moisture. Ear corn in a crib may be stored safely with several percent more moisture than shelled corn in a bin, so far as molds and loss of viability are concerned. However, rodents and insects cause much more damage to ear corn than to shelled corn.

The Rate at which the Corn Kernel gives up its Moisture. Data have been obtained by the Agricultural Engineering Research Branch in cooperation with the Illinois and Iowa Agricultural Experiment Stations but are not yet fully analyzed.

Rate of Air Flow through Shelled Corn in relation to air pressure. These data are essential for design of drying equipment. There are 3 main types of flow as follows: (1) Parallel flow, as when grain is placed at uniform depths over a perforated floor. Data on pressure-flow relationships for this type are reasonably complete (8, 14); (2) radial flow, as when air is delivered through a central duct and escapes uniformly in all directions, (15); and (3) non-uniform air flow where the air does not travel through uniform thicknesses of grain and the air paths are curved. An example is where air is delivered through ducts spaced at intervals on a bin floor. The air escaping directly above a duct travels a less distance than that escaping at other points. The time required for drying where the path is long is much greater than where the path is direct. (16) In comparing type (3) and type (1) air distribution, both the cost of installation and the cost of power must be considered. Further study of type (3) flow is needed.

Heat of Vaporization of Moisture in corn. Studies by the Agricultural Engineering Research Branch have shown that this is somewhat higher than the heat of vaporization of water. (9)

Basic Principles of Drying. Data on heat and moisture in air of different temperatures and relative humidities are available in steam tables and psychometric charts. However, not all of the heat carried by the drying air can be used. (17, 18) When dry air is forced through grain, a drying front is set up which moves through the grain mass, with the grain where the air enters drying first. (17, 18) There is a working knowledge of these principles, but further study is needed to accurately express rate of drying in mathematical terms. (See Hukill, p. K of these Proceedings).

Minimum Air Flow Rates in relation to condition of corn, air temperatures and relative humidity, etc. The Agricultural Research Service and the Georgia, Illinois, Iowa and Virginia Experiment Stations have cooperated on studies of minimum air flow rates with corn of different moisture contents and degrees of soundness under a range of temperatures and relative humidities. Similar studies have been made by a number of other Stations. There is a working knowledge of how to proceed with either heated or unheated air (10, 11, 19, 20 and Peterson and Simons, p. L of these Proceedings. Also various State publications), but additional research is needed to develop most economical procedures and to assure that the crop will not be damaged during drying.

Practical Grain Depth in relation to corn moisture, air temperature and relative humidity. This is closely related to minimum air flow rates. Power costs go up as depth of grain layer increases, but storage costs go down. (10, 11)

Fan Requirements. These are set by the minimum air flow requirements and the thickness of the grain in the drying bin or column and the resistance to air flow of the grain being dried. (10, 11, 14)

Forced Air Drying Units. As indicated above, public research has aimed at establishing the functional (heat, air-flow, air pressure and power) requirements for drying shelled corn but has done little on design of mechanical

units. However, the University of Georgia in cooperation with the Agricultural Research Service has designed and tested a small low-cost heated air drier. (21)

The Heat Pump for drying grain is being studied by the Minnesota and Purdue Experiment Stations and by the Agricultural Research Service in cooperation with the Kansas Station. (See Davis, p. 0 of these Proceedings).

Controls. Both safety and operational controls are important with heated air driers. (22) Time-clocks, thermostats and humidistats of standard or slightly modified design have been used in drying with unheated air to select the most favorable drying periods and thus increase drying efficiency.

Factors Limiting Drying Procedures

Viability loss during drying in relation to kernel moisture drying air temperature, relative humidity and time. There is good agreement on the injurious effects of temperatures above 110° F. on viability of moist grain (23) but comparatively little information on losses during drying at low temperatures.

Chemical changes during drying in relation to kernel moisture, air temperature and composition and time. (25)

Mold, fungi or bacteria development during drying in relation to kernel moisture, air temperature, relative humidity and time. Additional research is needed on rate of development of micro-organisms during drying. (See Christensen, p. H of these Proceedings and (39,40).

Changes in nutritional value during drying. The Animal and Poultry Husbandry Research Branch, Agricultural Research Service and the Nebraska Agricultural Experiment Station have conducted studies of the effect of drying at various temperatures on the nutritional value of corn. (24) (See Davis and Cabell, p. J of these Proceedings).

Effect of Drying temperatures on milling qualities of corn. The U.S.D.A. Northern Regional Research Laboratory has conducted studies on this subject. (25)

Structures for Drying and Storing Shelled Corn on the Farm

Advantages of storing shelled instead of ear corn, include (1) reduced bulk and weight of material to be stored; (2) lower building costs; (3) easier handling; and (4) improved protection against rodents and insects.

Requirements and design of buildings for storing shelled corn have been studied by several State experiment stations and the Agricultural Research Service. (26, 27, 28. Also State publications).

Pressures exerted on walls and floors of bins filled with shelled corn have been investigated by the Agricultural Engineering Research Branch in cooperation with the Iowa Experiment Station and the Stran-Steel Corporation. The study was made in bins where the depth of the corn was considerably less than the width of the bin. Pressures were measured on vertical surfaces, surfaces leaning toward the corn pile, leaning away from the corn pile, and curved toward the corn pile. (29)

Drying in Storage. Research in drying the small grains and shelled corn in the buildings where it is to be stored has been carried on by the Agricultural Engineering Research Branch and by the Alabama, California, Georgia, Illinois, Indiana, Iowa, Kansas, Louisiana, Maryland, Michigan, Minnesota, Nebraska, New Jersey, Ohio, Oregon, Pennsylvania, South Dakota, Texas, Virginia and Wisconsin Agricultural Experiment Stations. Much of this work has been done by State and Federal agencies working together, or in cooperation with industry. Some of the work has been assisted with funds furnished by the Commodity Stabilization Service, U. S. D. A. A number of publications, State and Federal, based on these investigations have been published. (10, 11, 30, 31, 32 and Peterson and Simons, p. L and Barre, p. M of these Proceedings. Also State publications). The number of stations interested in this problem shows both its importance and the influence of weather conditions at harvest time for different crops in the different geographical areas of the country. There is definite need for further study to determine the influence of climatic factors and to coordinate findings of the various research agencies.

Adaptation of building designs to accomodate air distribution systems, facilitate handling corn in and out, and permit use with other crops. The adoption of mechanical drying has shown the need for changes in storage structures to simplify installation of air distribution systems, reduce the labor required for handling the grain into and out of storage, and permit use of the buildings for drying and storing other crops when not used for corn. Work on this subject is underway at several Experiment Stations but much more is needed. (20, 32, 33 and Anderson, p. D of these Proceedings).

Batch driers for use with heated air. When heated air is used for drying wet shelled corn there are advantages in drying in batches, - usually 400 bushels or less at a time. Drying is completed in a few hours. The grain is then transferred to a storage bin, or hauled to market, and the drier is ready for another load. For satisfactory use the grain compartment must be built and equipped for quick filling and emptying. Batch driers of this type were designed and tested by the Illinois and Purdue Agricultural Experiment Stations in cooperation with the Agricultural Research Service. (34, 35) Several manufacturers now market units of this kind. (See Mitchell, p. N of these Proceedings).

Control of moisture migration. Work by the Agricultural Engineering Research Branch and the Agricultural Marketing Service in cooperation with several State Agricultural Experiment Stations has shown the importance of aerating stored dried grain to stop the concentration of moisture at the top surface of the bin. The principles are understood and equipment is available, but

further study is needed. Building designs incorporating these principles and equipment have not yet been fully developed. (36, 37) (See Holman, p. Q of these Proceedings).

Chemical and other changes in grain during storage. (38, 39)

Feeding shelled corn. Shelled corn has been fed to livestock for years and its advantages due to reduction of weight and bulk and flow characteristics are recognized. Field shelling and drying on a large scale open the way to new opportunities for cost savings through improved design of buildings and handling equipment. However, we have no record of research underway.

How important the cobs are in feeding cattle will be settled by farmers and livestock specialists.

Storing shelled corn in air-tight silos. This method is being used on a considerable percentage of the farms that harvest shelled corn and feed it on the farm. It is doubtful if this method will be adopted for use with high-moisture corn that is to be sold on the market since the corn develops a silage odor and must either be fed or dried soon after removal from the silo to avoid spoilage. (41) Favorable results with feeding high-moisture ground ear corn are reported in (42).

Economic and Management Problems

The Agricultural Economics Departments of the Illinois, Indiana, Georgia, North Carolina and perhaps other States are cooperating with the Agricultural Research Service in studies of costs of field shelling and mechanical drying as compared to other methods of harvesting corn. (43, 44) There is undoubtedly need for additional work of this kind. See Van Arsdall p. T of these Proceedings).

Another important matter is the coordination of this new technology with other farm practices, including rotation systems, varieties and growth periods of corn planted, selection of harvesting and drying equipment and design of buildings to handle more than one crop, and the like. Much additional work is needed on these subjects. (See Graves, p. S of these Proceedings).

Six Man-Years of Current Engineering Research on Drying and Storing Shelled Corn

This detailed listing of research problems may give the impression that a large number of workers are devoting their time to it. However, this is not the case.

The Agricultural Engineering Research Branch is using the equivalent of 6 full-time engineers on studies of storing and drying of all grains and seeds, including corn. Not more than half of their time is devoted to drying shelled corn. The State experiment stations have a larger number of men concerned to some degree with research on corn drying and storage problems, but in most cases this is only a small part of the man's total work.

Our best estimate is that not more than 6 professional man-years per year is being used by all public agencies on engineering problems related to drying and storing of shelled corn.

Data on the time devoted to biological and economic research on shelled corn drying and storage are not available.

Literature Cited^{3/}

1. "Moisture and Its Measurement", Hlynka, I. and Robinson, A. D., Chap. I, Storage of Cereal Grains and Their Products, American Association of Cereal Chemists, St. Paul, Minnesota, 1954.
2. "Developing Corn for Machine Harvesting", Jugenheimer, R. W., Crops and Soils, Vol. 1, No. 9, August - September 1949.
3. "The European Corn Borer and Its Control, USDA Farmers' Bulletin No. 2084, June 1955.
4. "Control of Insects Attacking Grain in Farm Storage", Cotton, R. T., USDA Farmers' Bulletin No. 1811, Rev. January 1942.
5. "Insects (attacking grain)", Cotton, R. T., Chap. V, Storage of Cereal Grain and Their Products, American Association of Cereal Chemists, St. Paul, Minnesota.
6. "Heating, Ventilating, Air Conditioning Guide", American Society of Heating and Air Conditioning Engineers, 1955 and previous editions.
7. "Air Conditioning Refrigerating Data Book", American Society of Refrigeration Engineers, 1955 and previous editions.
8. "Engineering Data on Grain Storage", Stahl, Benton M., ASAE Data; Agricultural Engineering Yearbook, 1955.
9. "Equilibrium Moisture and Heat of Vaporization of Shelled Corn and Wheat", Thompson, H. J. and Shedd, C. K., Jour. Agricultural Engineering, Vol. 35, No. 11, November 1954.
10. "Drying Shelled Corn and Small Grain with Heated Air", USDA Leaflet No. 331, 1952.
11. "Drying Shelled Corn and Small Grain with Unheated Air", USDA Leaflet No. 332, 1952.

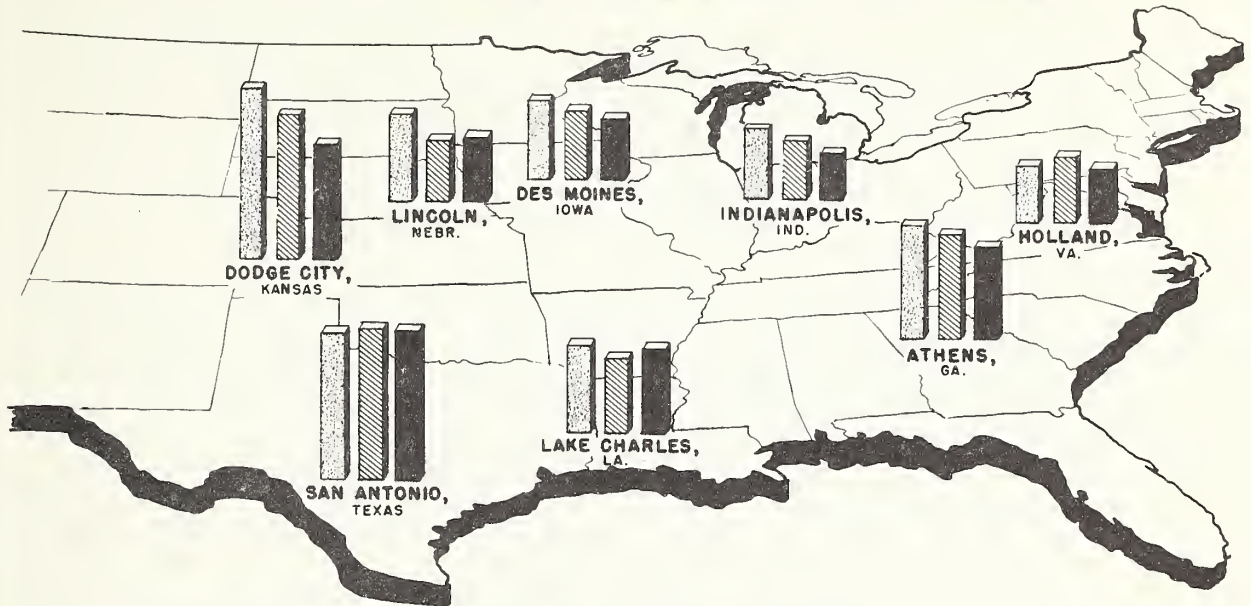
^{3/} This list of citations is not complete since many State and other publications were not at hand when the list was prepared.

12. "Drying Ear Corn with Heated Air", USDA Leaflet No. 333, 1952.
13. "Drying Ear Corn with Unheated Air", USDA Leaflet No. 334, 1952
14. "Resistance of Grains and Seeds to Air Flow", Shedd, C. K., Jour. Agricultural Engineering, Vol. 34, No. 9, September 1953.
15. "Radial Air Flow Resistance of Grain", Hukill, W. V. and Ives, N. C., Jour. Agricultural Engineering, Vol. 36, No. 5, May 1955.
16. "Non-Linear Air Flow in Grain Drying", Hukill, W. V. and Shedd, C. K., Jour. Agricultural Engineering, Vol. 36, No. 7, July 1955.
17. "Basic Principles in Drying Corn and Grain Sorghum", Hukill, W. V., Jour. Agricultural Engineering, Vol. 28, No. 8, August 1947.
18. "Drying of Grain", Hukill, W. V., Chap. IX, Storage of Cereal Grains and Their Products, American Association of Cereal Chemists.
19. "Minimum Air Flow Requirements for Drying Grain with Unheated Air", Foster, G. H., Jour. Agricultural Engineering, Vol. 34, No. 10, October 1953.
20. "Corn Drying and Storage in Tidewater Virginia", Givens, R. L. and Teter, N. C., Agricultural Engineering Research Branch, ARS, USDA, Mimeo. 1954.
21. "Culvert-Pipe Grain and Seed Drier for the Farm", Simons, J. W. and Smith, L. L., Circular No. 3, College Experiment Station, University of Georgia, 1953.
22. "Standards for Dehydrators and Driers", NFPA Standard No. 93, National Fire Protection Association, Boston, Massachusetts, 1954.
23. "Some Effects of Artificial Drying of Corn Grain", Ramser, J. H., Gausman, H. W., Dungan, G. H., Earle, F. R., MacMasters., M. M., Hall, H. H. and Baird, P. D., Plant Physiol. 27, 794-802, 1952.
24. "The Effect of Drying Temperature Upon the Nutritive Value and Commercial Grade of Corn", Hathaway, I. L., Yung, F. D. and Kiesselbach, T. A., Jour. Animal Science, Vol. 11, No. 2, May 1952.
25. "Studies on the Effect of Drying Conditions Upon the Composition and Suitability for Wet Milling of Artificially Dried Corn", MacMasters, M. M., Earle, F. R., Hall, H. H., Ramser, J. H. and Dungan, G. H., Jour. Cereal Chemistry, Vol. 31, No. 6, November 1954.
26. "Country Storage of Grain", Barre, H. J., Chap. VII, Storage of Cereal Grains and Their Products, American Association of Cereal Chemists.
27. "Storage of Dry Shelled Corn in Farm-Type Bins", Holman, Leo E., Barre, H., Cotton, R. T. and Walkden, H. H., USDA Circular No. 826, August 1949.

28. "You Can Store Grain Safely on the Farm", USDA Farmers' Bulletin No. 2071, 1954.
29. "Measurement of Grain Pressures on Bin Walls and Floors", Saul, Robert A., Jour. Agricultural Engineering, Vol. 34, No. 4, April 1953.
30. "Grain Drying with Forced Natural Air", Fenton, F. C., Stover, H. E., Whitehair, N. V., Kansas State College publication R.E. 12, June 1955.
31. "Grain Drying with Unheated Air", Hukill, W. V., Jour. Agricultural Engineering, Vol. 35, No. 6, June 1954.
32. "How to Dry and Store Grain and Seed on Georgia Farms", Simons, J. W., University of Georgia, (in press).
33. "General Purpose Crop Drying Building", Bruhn, H. D., Agricultural Experiment Station, University of Wisconsin, 1955.
34. "A Drying Bin for Shelled Corn and Small Grain", Foster, G. H., Purdue University Station Circular No. 365, 1950.
35. "Inclined Column Grain Drier", Holman, Leo E. and Andrew, Frank W., USDA Leaflet No. 314, 1951.
36. "Grain Cooling by Air", Hukill, W. V., Jour. Agricultural Engineering, Vol. 34, No. 7, July 1953.
37. "Mechanical Ventilation of Stored Grain", Robinson, R. N., Hukill, W. V., and Foster, G. H., Jour. Agricultural Engineering, Vol. 32, No. 11, November 1951.
38. "Chemical, Physical and Nutritive Changes (of grain)", Zeleny, Lawrence, Chap. II, Storage of Cereal Grains and Their Products, American Assoc. of Cereal Chemists.
39. "Respiration and Heating (of grain)", Milner, Max, and Geddes, W. F., Chap. IV, Storage of Cereal Grains and Their Products, American Assoc. of Cereal Chemists.
40. "Deterioration of Stored Grains by Molds", Christensen, Clyde M., Wallerstein Laboratories Communication, Vol. XIX, No. 64, 1956.
41. "Effects on Corn of Storage in Airtight Bins", Foster, G. H., Kaler, H. A. and Whistler, Roy L., Agricultural and Food Chemistry, Vol. 3, No. 8, p. 682, August 1955.
42. "High-Moisture Ground Ear Corn vs. Regular Ground Ear Corn With and Without Antibiotics for Fattening Steers, Beeson, W. M., Perry, T. W. and Honnold, R. E., Purdue University Agricultural Experiment Station Mimeo. A. H. 169, 1956.

43. "Factors Affecting the Cost of Storing Grain in Georgia", Rowan, S. W., Bunce, P. C., Brown, A. R., and Simons, J. W., University of Georgia, (in press).
44. "An Economic Analysis of Drying Wheat and Corn on Indiana Farms", Snodgrass, Milton M., Hardin, Lowell S. and Foster, George H., Station Bulletin 630, Purdue University, 1955.

FIELD DRYING POTENTIALS* FOR CORN



* Estimated from Fitzgerald's evaporation formula

Figure 1.--Comparative rates of evaporation at 8 typical locations at normal season for beginning corn harvest; also 2 weeks and 4 weeks before normal beginning. The higher the column the more rapid the evaporation in the field.

TEMPERATURE AND % RELATIVE HUMIDITY AT BEGINNING OF CORN HARVEST

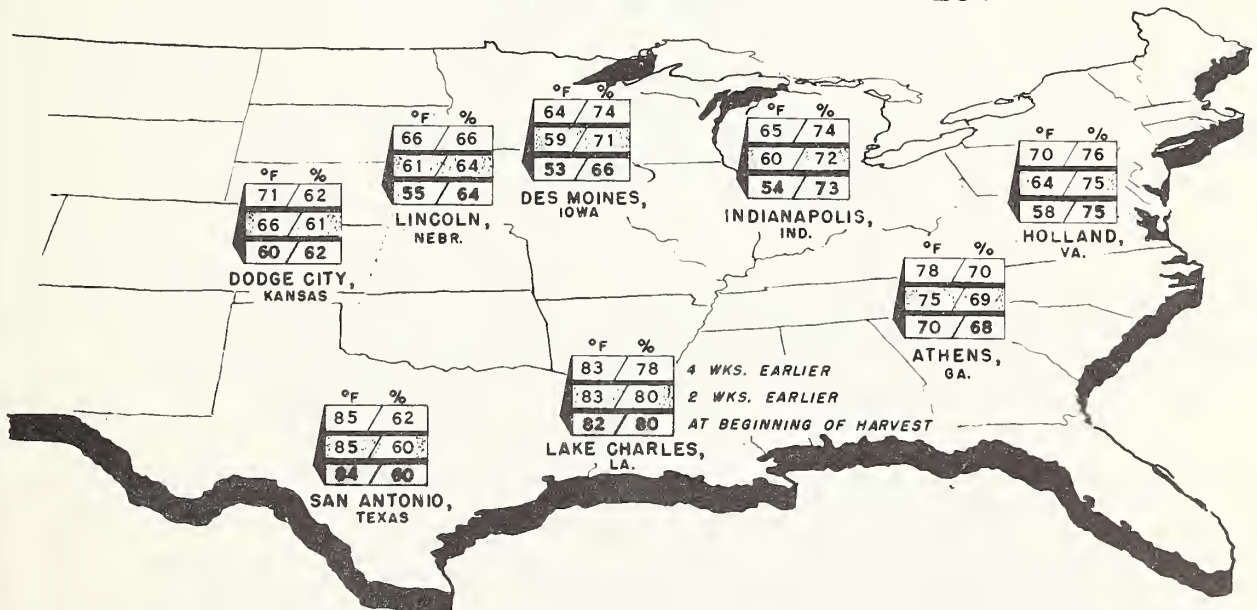


Figure 2.--Temperatures and relative humidities at 8 locations at normal time of beginning corn harvest, and 3 and 4 weeks earlier.

RESEARCH NEEDS

by

Professor C. K. Otis, Agricultural Engineering Department
University of Minnesota, St. Paul, Minnesota
and

R. R. Poyner, General Superintendent,
Farm Practice Research, International Harvester Company
Chicago, Illinois

Research in grain drying has progressed to the point where practical solutions to drying problems are now available and are being utilized to design successful systems. Therefore, field shelling of corn has become a practical reality. However, further refinements in techniques of field shelling, drying and storing corn call for still further basic information not yet available. Further research should be attacked on a broader front with workers in Engineering, Biochemistry, Entomology, Bacteriology, Livestock Nutrition, Plant Breeding, and Economics cooperating.

Under such a program investigations should be directed toward securing information on the following subjects:

A. General

1. Development of accurate, low-cost moisture-testing equipment and standard procedures for use in checking moisture content in the field and in storage.
2. Development of procedures for obtaining more accurate results with available moisture testing equipment.

B. Production

1. Development of corn varieties that will be better adapted to field shelling and mechanical drying procedures under various climatic and other environmental conditions.

C. Harvesting

1. Determination of the effects on quality, market grade, and suitability for various uses, of field shelling corn at varying moisture contents up to approximately 34%, particularly with respect to cracked kernels and foreign material.
2. Studies of gathering, snapping and sheller losses as related to varieties, moisture contents and basic mechanical designs.
3. Studies of the percent of maximum theoretical yield that can be expected from various varieties of corn grown under various conditions and harvested at various moisture contents before full maturity.
(See Miles, p. G of these Proceedings.)

D. Drying

1. Determination of the effects of drying air temperature on shelled corn of various initial moisture contents and degrees of maturity and soundness as related to nutritive value, milling quality and market grade. Data taken during tests should include a log of the dry bulb and wet bulb temperatures at selected locations in the grain mass.
2. Determination of maximum permissible time to complete "drying in storage" with and without supplemental heat, under the wide range of temperatures and humidities which may occur during the corn harvest season. Findings should be based upon such indices of deterioration as mold growth, loss of germination, fat acidity increase and loss of dry matter due to respiration, molds, fungi and bacteria.
3. Compilation and statistical analysis of psychrometric weather data for representative areas in the United States to obtain probability data for dew points, wet bulb depressions and wet bulb temperatures for any selected period of a few days up to one month. This information is needed for establishing the requirements of air flow and supplemental heat for "drying in storage."
4. Determination of factors affecting rate of moisture movement from the kernel.
5. Long range consideration of other approaches to drying including use of desiccants, use of solar energy for tempering the drying air, heat-pump drying and vacuum drying.

E. Structures and Facilities

1. Development of structures for (a) batch drying and (b) drying-in-storage, to accommodate efficient and economical air distribution systems and facilitate handling the crop in and out, keeping in mind that the structure may be used for other grains and forage as well as corn.
2. Study of other means of nutrient preservation such as gas tight storage, ensiling, and use of sterilizers or preservatives.

F. Economics and Farm Management

1. Determination of relative costs of harvesting, drying and storing shelled corn as compared to ear corn.
2. Determination of comparative costs of drying shelled corn by various methods in different parts of the country.
3. Adjustments in rotations, selection of varieties and other farm practices related to field shelling and drying of corn.

G. Marketing

1. Review of market requirements and grades as related to safe moisture contents for storage of corn.
2. Study of the effect of general use of field shelling methods on local markets for corn.

OUTLINE OF RESEARCH PROBLEMS RELATED TO FIELD SHELLING AND DRYING OF CORN ^{1/}

Compiled by
Farm Buildings Section, Agricultural Engineering Research Branch
Agricultural Research Service, U. S. Department of Agriculture

A. Agronomic and/or Entomological Problems

1. Reduction of pre-harvest losses
 - a. strength of stalk and shank
 - b. resistance to insect attack
 - c. insect control techniques and programs
2. Adaptation to field shelling
 - a. resistance to kernel damage
 - b. tightness of husk
 - c. attachment to cob
3. Relation of moisture content to maturity and yield

B. Characteristics of the Corn Kernel

1. Equilibrium moisture content in relation to air temperature and humidity
2. Rate of moisture loss from kernels fully exposed to air in relation to moisture content of kernels and air temperature, humidity and movement
3. Respiration rates in relation to moisture content and temperature
4. Specific heat
5. Heat transmission coefficients

C. Physical and Chemical Problems

1. Measurement of moisture content
 - a. sampling methods
 - b. laboratory determinations
 - (1) oven methods
 - (2) chemical methods
 - c. field determinations
 - (1) electrical resistance methods
 - (2) electrical capacitance methods
 - (3) methods for driving off moisture

^{1/} Practical solutions have been found for many of these problems but further progress is desirable.

2. Effect of kernel moisture content, air temperature and humidity and exposure time during drying upon
 - a. mold development
 - b. viability
 - c. chemical composition
 - d. nutritive value

D. Harvesting Problems

1. When to harvest
 - a. in relation to dropped ears, insect damage and other field losses
 - b. in relation to moisture content of kernels
2. Selection of harvesting equipment (influenced by topography, climate, size of field, type of corn)
 - a. picker, picker-sheller, or adapted grain combine
3. Selection of transport equipment and mechanical unloading device
4. Harvesting losses due to equipment
 - a. dropped ears or kernels
 - b. crushed and broken kernels
 - c. foreign material

E. Drying Problems

1. General
 - a. amount of moisture to be removed
 - b. rate of drying
 - c. volume change in relation to moisture loss or gain
 - d. heat of vaporization of moisture in corn

F. Drying with Air

1. Air pressure-flow relationship for parallel, radial, or non-uniform flow
2. Psychrometric relationships
 - a. heat input in drying air
 - b. efficiency of heat utilization
 - (1) heat available above wet bulb temperature
 - (2) relation of initial moisture content to heat available
3. The drying front
 - a. description
 - b. rate of movement - predicting drying time
4. Minimum air flow rates in relation to
 - a. condition of corn - moisture content and soundness of kernels

- b. air temperature and relative humidity
- c. type of operation - continuous, intermittent

G. Air Drying Systems

1. Type of system
 - a. batch - one-way vs. reversed air flow
 - b. continuous - parallel flow vs. counter-flow
2. Air distribution
 - a. plenum chamber with perforated floor or wall
 - b. air ducts
3. Practical grain depth or column thickness in relation to
 - a. air distribution system
 - b. cost of power
 - c. corn moisture
 - d. air temperature and humidity
4. Fan requirements
 - a. volume capacity
 - b. static pressure
5. Power requirements
6. Mechanical units
 - a. fans
 - b. heaters - oil, gas, coal
 - c. controls - safety, operating
7. Conveyors

H. Structures for Drying and Storing Shelled Corn

1. Structural strength, grain tightness, weather protection
2. Adaptation of design to accommodate
 - a. air distribution system
 - b. handling corn in and out
3. Control of moisture migration
4. Insect control
5. Rodent and bird control

J. Economic and Management Problems

1. Coordination of field shelling and drying with established farm practices
2. Investment and operating costs
 - a. volume required for various investments
3. Multiple use of equipment to reduce overhead costs
 - a. relation of shelled corn handling, drying and storage to similar operations with ear corn, other grains and forages
 - b. desirable combinations of structures, equipment and operating methods

CURRENT STATE AND FEDERAL PROJECTS RELATED TO
FIELD SHELLING, DRYING AND STORAGE OF CORN 1/

Agr. Exp. Station	Project Title	Leaders
Alabama	Comparative Yields of Early and Late Harvested Corn	J. L. Butt J. O. Helms
California	Determine Field Performance of Combines and Gathering Units Adapted to Harvest Field Corn	Roy Bainer J. R. Goss
Georgia	Corn Production and Harvesting Machinery	G. Futral J. Butler
Illinois	Improvement of Efficiency of Corn Harvesting Machinery: Combining Corn; Corn Picker Improvement	H. P. Bateman G. E. Pickard
	An Economic Analysis of Field Shelling and Farm Storage of Shelled corn (Agr. Economics)	J. E. Wills V. W. Davis R. N. Van Arsdall
Iowa	Functional Design Requirements and Performance of Farm Equipment - Comparison of Corn Harvesting Methods	K. K. Barnes
Louisiana	Harvesting, Handling and Drying of Rice, Small Grain and Grass Seed	F. T. Wratten H. T. Barr
Minnesota	Field Shelling of Corn	J. Strait R. V. Keppel A. J. Schwantes
Mississippi	Mechanization of Corn Production in the Hill Section of Mississippi	E. A. Kimbrough, Jr. F. E. Edwards
Missouri	The European Corn Borer, Ent. Project 270	A. K. Burditt, Jr.
Nebraska	Power Labor and Machinery Requirements for the Production of Corn	L. W. Hurlbut
Ohio	The Harvesting and Storing of Corn and Small Grain	W. H. Johnson
South Carolina	Design Development and Adaptation of Machines and Techniques in the Production of Corn	J. H. Ford

Agr. Exp. Station	Project Title	Leaders
South Dakota	Harvesting and Drying Corn	H. H. DeLong
California	Drying Small Grains with Unheated Air (corn, rice, milo)	S. M. Henderson
Georgia	Seed and Grain Drying Studies	J. W. Simons
Illinois	Crop Processing, Commercial Crop Driers	F. B. Lanham
	Drying Commercial Corn and Sweet Corn	J. R. Ramser
Indiana	The Relation of Drying and Storage Practices to the Deterioration of Grain	G. H. Foster G. W. Isaacs
	Determination of Drying Rates of Grain in Bulk Storages	G. W. Isaacs G. H. Foster
Iowa	Storage and Drying of Corn	K. K. Barnes
	Handling Grain Through Harvest, Drying and Storage	K. K. Barnes
	Farm Storage and Conditioning of Grains	K. K. Barnes
Maryland	Drying Corn with Unheated Air	G. J. Burkhardt
Michigan	Theory of Drying Agricultural Products	C. W. Hall
	Quonset Drying Studies	C. W. Hall
	Heated Air for Grain Drying	Brandt and Hall
	Use of Calcium Chloride for Corn Storage	C. W. Hall
Minnesota	The Use of the Heat Pump for Drying Farm Crops	H. A. Cloud
Missouri	Grain Drying	D. B. Brooker
Nebraska	The Use of Tempered Air for Conditioning Grain in Bulk Storage	G. M. Henderson
New Jersey	Grain Storage and Conditioning	M. E. Singley
Ohio	The Harvesting and Storing of Corn and Small Grain	W. H. Johnson
Oregon	Dehydration and Other Processing of Oregon Field Crops	Dale Kirk

Agr. Exp. Station	Project Title	Leaders
Pennsylvania	Air Distribution in Drying Hay and Grain	A. W. Clyde W. L. Kjølgaard P. M. Anderson
South Dakota	Crop Drying and Conditioning on South Dakota Farms	H. H. DeLong
Wisconsin	Design and Operation of Improved Crop Drying Structures	H. D. Bruhn C. O. Cvomev S. A. Witzel F. U. Duffe
* * * *		
Location of Federal Projects	Project Title	Leader & Agency
Experiment, Ga.	Mechanization of Corn Production and Har- vesting in the Southeast	J. H. Ford, AERB
Ames, Iowa	Pressures of Grain on Bin Walls, Floors and Structural Members	W. V. Hukill, AERB R. A. Saul
	Thermodynamics of Grain Drying under Farm Conditions	W. V. Hukill, AERB
	Airflow Requirements for Drying Grain with Unheated Air under Cornbelt Farm Conditions	W. V. Hukill, AERB
	Pressure Rate Relationships of Non- Parallel Air Flow Through Grain in Farm- type Bins	W. V. Hukill, AERB Norton C. Ives
Holland, Va.	Drying and Storage of Grain on Farms in the Eastern Tidewater Region	N. C. Teter, AERB R. L. Givens
Athens, Ga.	Airflow Requirements for Drying Grains, Ear Corn and Seeds With Unheated Air Under Farm Conditions in the Southeast	J. W. Simons, AERB B. C. Haynes, Jr.
Peoria, Ill.	Study of the Causes and Changes in the Solubility of Corn Protein Resulting from the Artificial Drying of High- Moisture Corn	F. R. Earle, NURB
Beltsville, Md.	Changes in Nutritional Values of Grains Due to Drying and Storage Treatments	R. E. Davis, APHRB C. A. Cabell, APHRB
Urbana, Ill.	An Economic Analysis of Field Shelling & Farm Storage of Shelled Corn in Illinois	C. W. Crickman, PERB R. Van Arsdall, PERB

REPORT ON USER TRAINING AND EDUCATIONAL NEEDS

by

J. B. Stere, Product Manager, Crop Drying,
New Holland Machine Company, New Holland, Pa.

It was generally concluded from the Round Table discussion of last evening that the basic User Training and Educational Needs are as follows:

1. A more complete understanding of the economic advantages and disadvantages of field shelling, drying and storing.
2. Education in the limits of grain moisture content for field shelling, considering crop quality and economy.
3. Training in (a) how to take representative samples of corn for moisture testing; and (b) how to use moisture testing equipment to obtain more accurate moisture determinations.
4. Simplified aid in selecting drying capacity that will best meet farmers' requirements.
5. Aid in applying drying equipment to satisfy harvesting, handling and storing facilities.
6. Aid in formulating the principles for systems that are sound, efficient, practical and considerate of the related factors.

Correlating drying with other elements

We need training in a technique that involves more than one pattern. It involves, reaches out and touches many other phases of agriculture. Information is available but must be presented in a manner that is simplified and understandable. We find it most difficult to put it into terms that others can understand.

The educational program must simplify the terminology; for instance, explain the difference between "supplemental heat" and "heated air" which is still not clear to me. Make it simple and understandable. When this has been done to the point where it seems simple, get someone who knows nothing of the procedure and see what they think of it.

We need unified support and should use available resources, with the educational and training field aids simplified so as to disseminate sound information put in simple terms.

Discussion

(Pinches) The question of terminology is one which we ran into immediately when we started planning this program. There is a committee in the American Society of Agricultural Engineers which is working toward the development

of an acceptable common language for at least part of the questions on which we have thus far been indefinite as to terms. Professor Hall of Michigan State University is on that Committee.

(Hall) If you have strong feelings about the use of any of these terms, please convey your thoughts to the Secretary of ASAE and he will forward them to us.

(Pinches) Let's give support to this committee of ASAE which is trying to reach an agreement so that when we use certain expressions the other fellow understands what we mean.

(Lehmann) A technique is needed for getting instruction to the level where it is given to the farmer. Dealers need thorough instruction on equipment they are selling to the farmer. The farmer depends on salesmen. More training is necessary for salesmen. The extension programs in most states attempt to work with managers because they make contacts through their salesmen. It seems to me that one of the very basic needs is to work out programs so that extension personnel and representatives of industry can join forces at that level and distribute this knowledge most effectively.

(Stere) Educational institutions are the people we should work through in preparing and conducting the educational program. But that doesn't mean that the educational institution will have to initiate the thinking. Any one of the organizations that have a direct or allied interest can spark a cooperative educational program.

THE DIFFUSION AND ACCEPTANCE OF NEW IDEAS AS RELATED TO FIELD SHELLING AND DRYING OF CORN

by

Dale O. Hull
Extension Agricultural Engineer
Iowa State College

Last year our Iowa State College sociologists cooperating with other sociologists in the North Central Region made an extensive study of the methods by which farm peoples accept new ideas. I think it is appropriate for us to use this information and to analyze it with regard to the acceptance of field shelling and drying by corn belt farmers. This is not an individual practice, such as the use of fertilizer or use of an improved seed variety which requires purchase of only limited amounts of mechanical equipment. The practice we are considering involves a technique and large adjustments in machine management. For successful adaptation on the farm it requires cooperation between federal agencies, extension services in the states, state experiment stations and industry in particular.

The Diffusion Process

In the diffusion process the first indication that a farmer will (1) accept a new idea is when he becomes aware of the new practice. If he shows interest then he seeks (2) more information as to how the practice is performed. Later on he will make a decision (3) to try the practice and perhaps the next year will (4) institute it on his farm on a trial basis. The fifth step in the diffusion practice is adoption by the farmer as a regular farm practice.

When the farmer first becomes aware of a new practice he lacks details which must be obtained. He first learns of the new practice from such mass media as farm papers, farm magazines, newspapers and from radio and TV. Studies indicate that 50% of the ideas that farmers adopt come from the mass media presentations. The second source of new ideas is his government agencies such as the agricultural extension service, the vocational agriculture teachers, the home economists and to a lesser extent from the soil conservation service and the agricultural conservation program agencies. A third important individual is the salesman representing industry. Usually he contacts the first farmers as a follow-up in a letter from the farmer. The fourth source of information is from neighbors and friends close by.

After he becomes aware of the practice he seeks information regarding its application. He analyzes the possibilities of the practice on his farm. Later on after much mental work he weighs the alternatives as to whether or not the practice is satisfactory for him and perhaps he decides to give it a try. Usually he decides on a trial at drying corn possibly taking a load or two of corn to a country elevator equipped for drying. He learns that drying is a good practice and later on decides for adoption, purchasing a field sheller and grain drying equipment after he sees that drying and shelling is a profitable practice.

Four Groups Spark the Diffusion Process

There are 4 groups of individuals who distinctly form together as a practice is adopted in the corn belt. In the case of hybrid seed corn these might be classified as follows: The (1) innovator, the (2) early adopters, the (3) informal community leaders and then later the (4) majority of the farmers.

The Innovator

The innovator is the man who will try almost anything new. He is the farmer who writes cards and letters to manufacturers following up on advertisements and from what he has learned from mass media regarding a new practice. He is the farmer first contacted by sales representatives of industry. He comes from a good community, has a large farm, has high educational and social status, and is from a well-established family. In many cases the family entered the land and has owned it for many years. He is active in community work and does extra community work beyond that usually expected of a citizen.

His community. The neighborhood from which the innovator comes is above average in farm size. There is an extraordinary amount of community activity going on with good churches, schools and social clubs being distinct characteristics. The neighborhood is better than average from a financial standpoint.

The innovators represent only a small percentage of the total number of farmers. In the hybrid corn study, as I recall, innovators represented only 5% of the total number of farmers.

Early Adopters

The early adopters are younger farmers and will follow the innovator into the corn drying field. The time interval varies widely depending upon the practice. They are young farmers with higher than ordinary education, perhaps some of them having college degrees. Because of their educational connections they participate extensively in social activity. They are wide readers of magazines and newspapers and are distinctively characterized by their following new bulletins which are issued by public agencies. They are active in farm co-ops, soils districts, farm organizations and in the Agricultural Stabilization and Conservation program.

This group is contacted by the mass media, by public agencies, salesmen and others, and in addition contact the innovator for more information on the practice to be adopted.

Informal Community Leaders

The most important group are the informal leaders. After informal leaders in the community begin to adopt field shelling and drying, the practice is becoming well-established and gains in sales of equipment will come forward rapidly. We have many communities where the practice of field shelling and drying is well-established. It is well past the innovator stage and through the adopter stage with informal leaders now taking over.

In some spots as many as 30 or 40% of the farmers are doing something about corn drying. However these spots are widely scattered, at least in my home state.

The informal leader is usually not an innovator. He is early to adopt practices and usually adopts more new practices than the average farmer. He has average education and farming experience and of medium high social and economic status. He is a wide reader of newspapers and magazines.

When the informal leaders, who are not usually recognized publicly as leaders in communities, begin to accept a practice it rapidly becomes established.

Majority of Farmers.

The fourth group is the majority of the farmers. Most of these eventually adopt the practice although there are many who are non-adopters. These men are older, have less education, usually not their fault, and participate in fewer social activities. They do not read as many bulletins issued by the public agencies and subscribe to fewer magazines and farm papers. In general, they are less active in farm organizations.

It is important for those of us who are doing educational and training work in corn drying to recognize that a practice is not always accepted rapidly and very often is not accepted at all. Certainly the field shelling and drying of corn will be accepted by farmers in the corn belt. However I want to point out that manufacturers should not become discouraged because sales volume is slow to develop. Certainly other groups have experienced the same problems. The automobile industry has worked for many years to sell the public on the automatic transmission. I think that another 10 years will see great changes with regard to the adoption of field shelling and drying in the corn belt.

